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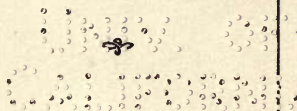
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THE
ELEMENTS

SPECULATIONS AS TO
THEIR NATURE AND
ORIGIN



BY
SIR WILLIAM A.
TILDEN



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THE ELEMENTS

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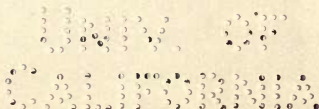
BY

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PREFACE

WHEN in October last, by invitation of the Council of the Chemical Society, I gave the Mendeléeff Memorial Lecture, it was my privilege to proclaim, on behalf of English science, a eulogium of the famous Russian chemist. It would have been inappropriate to the occasion to have discussed in much detail the various hypotheses which from time to time have been framed in connection with the idea of evolution as applied to the elements, and all the more so for the reason that this idea seems to have been always repugnant to the mind of Mendeléeff himself. I am therefore glad of the opportunity afforded by this series to place side by side ideas which have been long fermenting in my own mind and in the minds of other chemists. In doing this I do not pretend to have treated

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the subject with any approach to historical completeness. The literature connected with the subject is very extensive, and is still expanding.

What I have tried to do is to render the discussion intelligible to the very large number of educated persons possessing an elementary knowledge of chemistry, as well as to offer a few suggestions to expert chemists. In doing this I have had to exercise my own judgment in the selection of those contributions to the inquiry which seemed to possess the greatest importance. I am conscious that this lays me open to criticism, alike from those whose views have been discussed and from those who have not been mentioned, as well as from those who see points of attack in the exposition of my own notions. Such, however, is always the position of one who ventures to enter a field so open to speculation as the subject of this little book.

Here we are dealing only with the physical

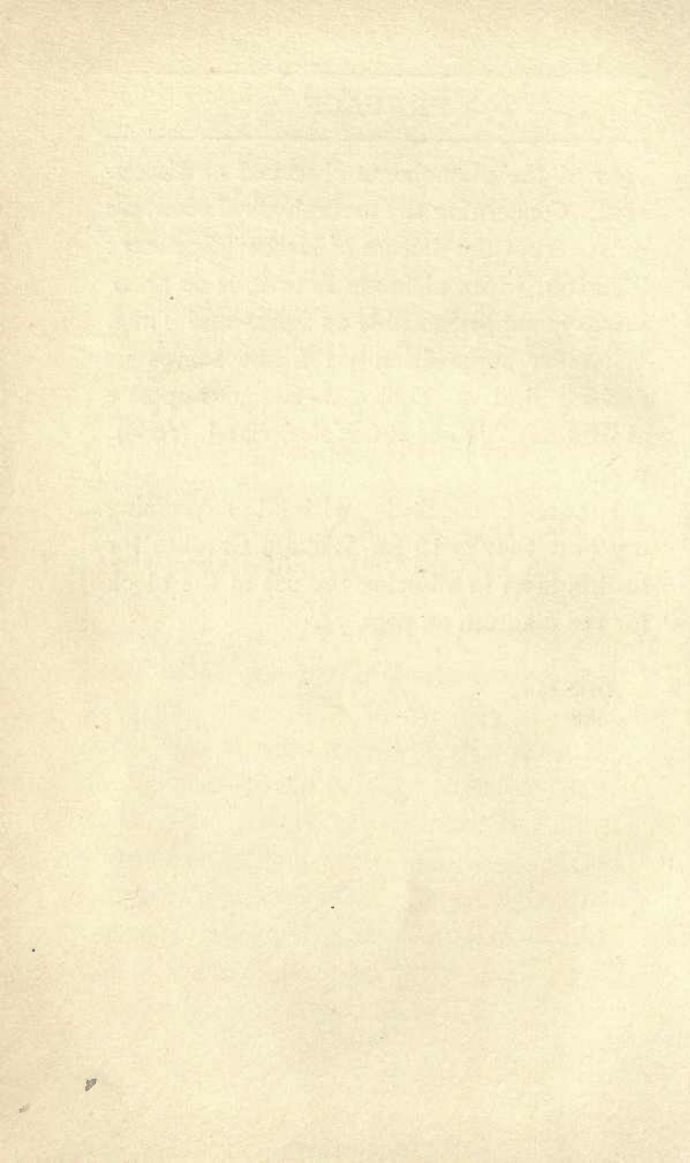
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view of the phenomena observed or discovered. Concerning the metaphysical view, we must accept the dictum of Herbert Spencer : “ Matter, in its ultimate nature, is as absolutely incomprehensible as Space and Time. Whatever supposition we frame leaves us nothing but a choice between opposite absurdities.” (*First Principles*, vi. ed. (1900), p. 46.)

I cannot conclude without expressing my best thanks to Sir William Crookes for his kindness in allowing the use of the block for the diagram on page 74.

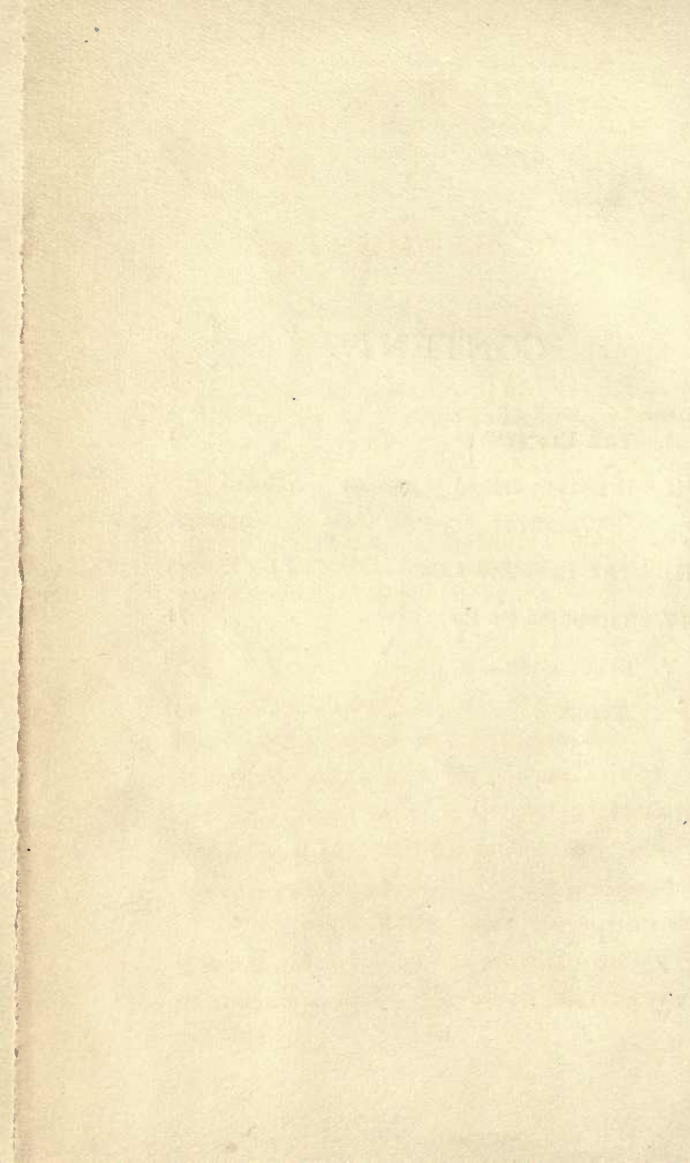
W. A. T.

April, 1910.



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THE ELEMENTS

CHAPTER I

"CHEMICAL analysis and synthesis go no farther than to the separation of particles one from another and to their reunion. No new creation or destruction of matter is within the reach of chemical agency. We might as well attempt to introduce a new planet into the solar system, or to annihilate one already in existence, as to create or destroy a particle of hydrogen. All the changes we can produce consist in separating particles that are in a state of cohesion or combination, and joining those that were previously at a distance."

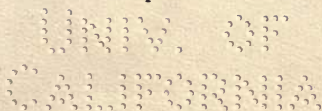
DALTON'S *Chemical Philosophy* (1808), vol. i, p. 212.

THE ancient Greek philosophers, and probably others in earlier times, from the contemplation of the order of things unfolded before them, were led to the discussion of problems which could never have been resolved by the methods alone available in the early ages of the world.

The substitution of artificial for natural conditions in the study of phenomena, in

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I



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other words the use of experiment, is the characteristic of modern philosophy, and without it the modern student would be in nearly the same position as Democritus and Leucippus, and would doubtless remain in the same dialectical obscurity.

But experimental physics and chemistry, comparatively recent as they are in their origin, have led us far beyond anything which in ancient times could have been conceived as possible in respect to positive knowledge of the constitution and order of the visible universe. Questions as to the nature and origin of matter can therefore be treated at the present day as within the range of reasonable subjects of study, to which answers can be framed in terms which, if not final, are at any rate general, consistent, and intelligible.

Chemistry teaches us that all the immense diversity of matters which go to make up the solid earth, with its attendant ocean and atmosphere, together with the sun and all

DEFINITION OF ELEMENT

the heavenly host of stars and nebulae, are composed of a limited number of distinct substances which are called "elements."*

* Perhaps it may not be superfluous to remind the reader that the word "element" has received at different periods in the history of philosophy several distinct applications. The four elements—fire, water, earth, air—of the Aristotelean system, were succeeded in the sixteenth century by the salt, sulphur, and mercury, or the *tria prima* of the alchemists. To Robert Boyle we owe the connotation now universally attached in scientific language to this word, which is applied to those substances, about eighty in number, from which, by the operation of ordinary chemical processes, only one kind of matter can be obtained. Iron, for example, is placed among the elements, while iron rust is a compound of two elements, iron and oxygen. Notwithstanding the belief now generally entertained that some of the so-called elements subsist in a condition of continuous decay, this application of the word is convenient and is likely to be retained for some time to come.

The state of knowledge and opinion in Boyle's time may be inferred from the following caustic passage in his famous book entitled, *The Sceptical Chymist*" (1680), pp. 23, 24. "The doctrine of the four Elements was framed by Aristotle after he had leasurately considered those Theories of former Philosophers. . . . Nor has an Hypothesis so deliberately and maturely established been called in Question till in the last Century *Paracelsus* and some few other sooty Empiricks rather than (as they are fain to call themselves) Philosophers having their eyes darkened and their Brains troubled with the smoak of their own Furnaces, began to rail at the Peripatetick Doctrine, which they were too illiterate to understand, and to tell the credulous World

THE ELEMENTS

Many of these are familiar in daily life. Such metals as pure gold, silver, iron, copper, lead, tin, zinc, etc., are elements, as also are the atmospheric gases oxygen, nitrogen, argon. These are for the most part capable of associating together in chemical "compounds," in which the properties of the "elements," as commonly known, are concealed and substances of different aspect and properties result. Water, for example, is a very different thing from the oxygen and hydrogen into which by appropriate treatment it can be wholly resolved. The change of a compound into elements is always accompanied by a redistribution of the energy inherent in the matter concerned and in the matter with which it is in contact, or in the that they could see but three Ingredients in mixt Bodies ; which to gain themselves the repute of Inventors they endeavoured to disguise by calling them instead of Earth and Fire and Vapour, Salt, Sulphur, and Mercury ; to which they gave the canting title of Hypostatical Principles, but when they came to describe them they showed how little they understood what they meant by them by disagreeing as much from one another as from the truth they agreed in opposing."

DIVISIBILITY OF MATTER

“ ether ”* in which all are immersed. In the majority of cases the separation of elements from a compound is attended by absorption of energy, which is given out again in the form of heat if they are allowed or caused to combine. Water, for example, when strongly heated gives oxygen gas and hydrogen gas, and these if allowed to combine again reproduce water, at the same time giving forth heat equivalent in amount to the energy used up in the destruction of the compound.

The old question whether the divisibility of matter is finite or infinite, debated throughout ancient and medieval times without the possibility of reaching a conclusion, has been in modern times decisively answered by physics and chemistry.

It is no longer a subject of debate, but it is with practical unanimity agreed that the texture of all kinds of matter is not continuous, but is discrete or granular. Hence

* See Lodge, *The Ether of Space*. This series.

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the Atomic and Molecular Theory, which asserts that there is a limit to divisibility, and the coarseness or fineness of the atomic particles is merely a detail.

The nature of the evidence on which this conclusion is based is derived wholly from modern experimental investigations, on the one hand, of the properties of liquids and especially of gases ; and on the other, from the establishment of the fundamental quantitative laws of chemical combination.

The facts of gaseous and liquid diffusion are familiar, and alone they are sufficient to prove that in a mass of any fluid portions of it are constantly moving about, and that these moving portions are very small is indicated by their passage through the pores of earthenware, or even of various membranes.

A hundred years ago it was discovered that when two substances unite to form a chemical compound the ratio between the quantities of the two so uniting is constant.

DEFINITE PROPORTIONS

That is to say, any selected chemical compound consists of two or more elements associated together in proportions which never vary. Water, for example, is always composed of hydrogen and oxygen in the proportions of 1 part by weight of the former to 8 parts by weight of the latter, and no kind or variety of water is known in which the two components are united in different proportions. There is indeed another compound of hydrogen with oxygen, in which the weight of the oxygen is sixteen times that of the hydrogen, but this compound is wholly different from water in all its properties. It will be noticed that the proportion of oxygen in the second compound is exactly twice the proportion in the former. There are many examples of the same kind, and in all such cases when two substances unite in several proportions it will be found that the proportion of one element in the successive compounds are multiples of the proportion of this element

THE ELEMENTS

occurring in the first of the series. Compounds are known containing 28 parts of nitrogen combined with 16 parts of oxygen, and with twice, three times, four times, and five times 16 parts of oxygen in the successive stages.

This is a simple illustration of the operation of the law of multiple proportions, and for this no satisfactory explanation has been given except that which is furnished by the Atomic Theory of Dalton.

Dalton's theory was announced in his *New System of Chemical Philosophy*, which he published in 1808. But for many years the system made little progress owing to the fact that on the one hand Dalton and his contemporaries had no standard by which the relative weights of the atoms of different elements could be determined ; and on the other hand because a distinction in terms, generally acceptable to physicists and chemists, had not been established between the ultimate particles of ele-

ATOM AND MOLECULE

ments and of compounds. While it is perfectly justifiable to speak of an atom of water, meaning thereby the particle which if further subdivided would be no longer water, but would become a mixture of hydrogen and oxygen, yet this use of the word atom is liable to lead to confusion, and another term was required. This was provided later by the use of the word molecule, which signifies the smallest particle of an element or of a compound capable of independent existence, the term atom being reserved for the smallest portion of an element ever found in a molecule.

The conception of the molecule as distinct from the atom we owe to Avogadro, who, in 1811, put forward a hypothesis which has only in much later times been generally accepted by chemists. A famous French chemist, Gay-Lussac, established by experiment the law with which is generally associated his name, namely, that when gases unite together the volumes which unite stand to

THE ELEMENTS

one another in a simple ratio. For example, one volume of hydrogen combines with one volume of chlorine, producing two volumes of hydrogen chloride gas, one volume of hydrogen chloride combines with one volume of ammonia, two volumes of hydrogen combine with one volume of oxygen, etc. In order to explain this discovery Avogadro assumed that equal volumes of different gases, at the same temperature and pressure, contain the same number of molecules, a statement which is often expressed otherwise by saying that the densities of gases are proportional to the molecular weights of the substances of which they consist.

If this be accepted then a means is provided whereby atomic weights may be determined, and for all those elements which are capable of yielding gaseous or vaporisable compounds the atomic weights so determined are comparable with one another and with a common standard. All that is fur-

STANDARD FOR ATOMIC WEIGHTS

ther necessary is to agree upon some one element the atomic weight of which may be adopted as the unit. For this purpose hydrogen, as forming the lightest gas known, and as the element which enters into combination in the smallest known proportion, has during the last half century been accepted. Latterly for reasons which at this point need not be considered, the scale of hydrogen as the unit, $=1$, has been, by international consent, exchanged for one in which the atomic weight of oxygen is taken as exactly 16, and consequently that of hydrogen becomes 1.008.

The Atomic Theory is further supported by the remarkable achievements in the domain of stereochemistry which have been recorded during the last thirty years. Notwithstanding the large number of hypotheses which have been put forward no explanation is yet established of that property of atoms which is called their valency. But though it is not possible to

THE ELEMENTS

explain what is the nature of the link by which atoms unite together in chemical combination, it is possible by the aid of the assumption that matter consists of atoms united into groups or clusters, called molecules, and the further assumption that when these atoms occupy in space certain positions relatively to one another, to show that the molecules so constituted exhibit certain recognisable properties. It is now a familiar operation to proceed to build up such congeries of atoms with the certainty that the resulting compound will exhibit the expected properties.

And, further, it has been shown in a large number of cases that, given a limited number of atoms, a limited number of arrangements are alone possible, and any attempts to produce other compounds in which the rules imposed by valency are not complied with result in failure.

This is not the place for an exposition of the results of modern stereochemical in-

STEREOMERISOMERIC COMPOUNDS

vestigation, but for the sake of illustration a single familiar example may be quoted. There are four kinds of tartaric acid, namely: (1) common tartaric acid which rotates the plane of polarisation of light toward the right ; (2) another variety which rotates to the left ; (3) racemic acid, which has no rotatory power, but is optically inactive because it consists of a mixture in exactly equal quantities of the two active varieties which are separable by simple processes from each other ; and (4) an optically inactive form of tartaric acid which is not resolvable into two active forms. These acids consist of carbon hydrogen and oxygen in the proportions represented by the formula $C_4H_6O_6$, and they agree in chemical reactions which are expressed by saying that they are dihydroxy-succinic acids, and hence that they consist of the atomic clusters or radicles represented by the symbols C_2H_2 , $2HO$, and $2CO_2H$.

Two of these acids act on polarised light

THE ELEMENTS

in such a way as to show that their molecules must be unsymmetrical in opposite senses, the one corresponding to a right-handed spiral, the other to a left-handed spiral. In racemic acid the dextro-rotatory effect of one of these molecules is exactly neutralised by the levorotatory effect of the other. The other inactive compound must be accounted for in a different way, namely by the assumption that the *internal* parts of each molecule are so arranged that the lopsidedness produced by one constituent is counterbalanced by another so situated as to act in the opposite direction relatively to the centre of gravity.

The phenomena exhibited by the tartaric acids were discovered by Pasteur, about 1850, and he anticipated to some extent the hypotheses introduced and accepted twenty-five years later. But it was not till the idea of attributing to the atom of carbon a peculiarity of configuration was published almost simultaneously by Le Bel and Van't

THE CARBON ATOM

Hoff* that the atomic and molecular hypotheses became qualified to explain all the facts. The four units of valency of an atom of carbon being supposed to act only in certain directions represented by the straight lines drawn from the centre of a regular tetrahedron to its solid angles, it was found possible to account for the right- and left-handed optical properties of the tartaric acids and the many other similarly active compounds.

It might of course be said that in making use of this conception one hypothesis is employed to support another, but the facts which fit in with the theory are so numerous and its use has led to so many discoveries of compounds, the existence of which was previously unsuspected, that supposition is changed into conviction that this is really

* "Sur les formules de structure dans l'espace," J. H. Van't Hoff in *Archives Neerland*, ix (1874), p. 445. "Sur les relations qui existent entre les formules atomiques des corps organiques, et le pouvoir rotatoire de leurs dissolutions," J. A. Le Bel, *Bulletin Soc. Chim.*, Paris, xxii (1874), p. 337.

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the physical explanation of the observed facts.

Further support for the theory is derived from the results of applying to the compounds of elements other than carbon similar methods of investigation. For it has been found that nitrogen, sulphur, tin, and probably some of the metals are also capable of giving rise to isomeric compounds of which the optical and other physical relationships finds a corresponding explanation.

Having briefly reviewed the chief considerations which have led to the adoption of the Atomic Theory, it is proper to survey equally briefly the facts and arguments by the aid of which chemists have finally arrived at a system of numbers which represent the relative masses of the atoms of elements. These numbers are really ratios or fractions in which the denominator is suppressed, being understood to be throughout the value of the atomic weight of the element hydrogen, the smallest at present known. In Dalton's

STANDARD FOR ATOMIC WEIGHTS

time, and long afterwards, the numbers called atomic weights were in reality the chemical combining ratios of the elements, and these might or might not coincide with the numbers which are now chosen in accordance with the results of the application of rules agreed upon since that day. It is not necessary to trace all the various suggestions put forward during nearly half a century with the object of reducing these figures to order. It is sufficient to say that to Cannizzaro is due the credit of successfully convincing the chemical world of the desirability of adopting a uniform standard, and of bringing to a focus the proposals of other chemists, especially those of Gerhardt, Odling, Williamson, and others, based on "the corner-stone of the modern theory of molecules and atoms,"* the theory of Avogadro on the constitution of gases.

The process by which an atomic weight is

* Cannizzaro : Faraday Lecture, 1872. *Trans. Chem. Soc.*, 25, 946.

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determined resolves itself into two distinct parts, of which the first is dependent upon accuracy in experiment; the second on the selection of appropriate theoretical considerations.

The first requisite in all cases is the determination of the chemical combining ratio of the element, or what is frequently, though not very correctly, called the equivalent.

This is accomplished by estimating, with every precaution to secure accuracy, either the proportions in which two elements unite together, or the amount set free by the process of electrolysis from a solution of the compound and a comparison of the weight thus deposited with the weight of some standard substance, such as silver, set free at the same time by the same current. The proportions in which oxygen and hydrogen unite to form water have been repeatedly investigated, as also the composition of hydrogen chloride, and the chlorides and oxides of many metals, as well as non-metals.

AVOGADRO'S RULE

In fact, whenever a compound can be obtained in a pure definite state, in which it can be readily weighed, its composition has been the subject of laborious investigation, and thus a series of numbers have been arrived at which represent with a greater or less degree of accuracy combining weights of all the elements.

The second step is to choose a multiple of the number representing the combining weight, such that the product complies with one or all of the following rules.

1. Application of the rule of Avogadro: The atomic weight of an element is the smallest quantity ever found in two volumes of the vapour of any of its vaporisable compounds, the bulk of one part by weight of hydrogen being taken as one volume.

Practically this amounts to comparing the densities of the vapours of the several compounds containing the element in question with the density of hydrogen as the

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unit. The results in the case of carbon may be tabulated as follows :

Compound containing Carbon.	Density H = 1.	Density × 2 or weight of 2 vols.	Weight of Carbon in 2 vols.
Marsh gas . . .	8	16	12
Ethane . . .	15	30	24
Carbon monoxide	14	28	12
Carbon dioxide .	22	44	12
Alcohol . . .	23	46	24
Ether . . .	37	74	48
Aniline . . .	46.5	93	72

The atomic weight of carbon is taken as 12, because this is the smallest weight of carbon ever found in two volumes of the vapour, that is in a molecular weight.

2. Application of the rule of Dulong and Petit.

While the relation of specific heat to atomic weight is expressible in the great majority of cases by the equation $S.H. \times A.W. = \text{constant} = 6.4$ (approx.) this does not hold good save under exceptional conditions for carbon and several other elements. But

DULONG AND PETIT

it is especially useful in connection with the metals, many of which do not form volatile compounds, and hence cannot be tested by the hypothesis of Avogadro. It is, however, most important to notice that in those cases, tin, mercury, zinc, for example, in which both methods can be applied, the atomic weight deduced from the application of one rule is identical with that which is deduced from the application of the other.

3. The observation of isomorphism is often a useful guide. The case of vanadium furnishes an interesting example. Fifty years ago this element was supposed, on the authority of analyses made by Berzelius, to belong to the same family as chromium, and its highest oxide was represented as a trioxide. But the mineral vanadinite, consisting of lead vanadate and chloride, was shown to crystallise in the same form as apatite or calcium fluo-phosphate, and pyromorphite or lead chlorophosphate, and in some cases to crystallise with these

THE ELEMENTS

minerals in all proportions. Hence it appears that vanadic acid is the crystallographic representative of phosphoric acid, and vanadic oxide like phosphoric oxide is a pentoxide. The whole chemical history of the compounds of vanadium was shown by Roscoe to conform to this view, and hence the atomic weight of vanadium was shown to be approximately 51, instead of 137 as previously supposed, and the substance represented by Berzelius as the metal turned out to be an oxide.

4. The position of the elements in the periodic scheme, to be described later, has been frequently turned to account within the last forty years. Beryllium (glucinum) affords an illustration of the application of this principle. Formerly supposed to be related to aluminium this metal was represented as forming a sesquioxide, Be_2O_3 , and having the atomic weight 13 (approx.). By reference to the table (p. 46) it appears that between carbon (at. wt. 12) and

USE OF PERIODIC SCHEME

nitrogen (at. wt. 14) there is no appropriate place for an element with the properties of a metal, nor indeed for any element whatever, if the scheme truly represents the mutual relationships of the elements. This remark led to further investigation of the physical and chemical properties of beryllium with the result that, from observation of the specific heat of the metal at various temperatures and a study of the characters of its salts, this element was shown to be related not to aluminium, but to magnesium, and to have an atomic weight 9.1.

Other methods and considerations are resorted to in special cases, but these are more appropriately set forth at length in the usual textbooks of chemistry. All that need be noted specially in this place is the fundamental fact that the numbers now recognised by chemists as representing the relative values of atomic weights have been calculated upon the same scale and are all

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adjusted to a common standard. As already stated, a period exceeding half a century elapsed from the introduction and adoption of the Atomic Theory into chemistry before this uniformity was secured and before the relations of the elements to one another and to a general comprehensive scheme was recognised. It is out of a study of this scheme that modern speculations as to the nature and origin of all matter have chiefly originated.

CHAPTER II

INTERRELATIONS AMONG ATOMIC WEIGHTS

“WE think in relations.”—HERBERT SPENCER. *First Principles*, vi (ed. 1900), p. 145.

FROM the previous chapter it is obvious that until the atomic weights had been reduced by common consent to one uniform scale or standard, it was not possible to perceive any *general* law governing the whole. Nevertheless many attempts were made to discover relations among the numbers in use. The first and one of the most famous of these is known in chemical literature as “Prout’s hypothesis.”* This assumes that the atomic

* *Ann. Phil.*, vi (1815), 321 ; vii (1816), 111.

Prout’s views were published anonymously under the title, *On the Relations between the Specific Gravities of Bodies in their Gaseous State and the Weights of their Atoms*.

His thesis is summed up in the following passage (loc. cit. vii, 113): “There is an advantage in considering the volume of hydrogen equal to the atom, as, in this case, the specific gravities of most, or perhaps all, elementary substances (hydrogen being 1) will either exactly coincide with or be some multiple of the weights of their atoms.”

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weights of all the other elements are multiples of the atomic weight of hydrogen.

The case of chlorine, of which the atomic weight has always been known to be approximately $35\frac{1}{2}$, proved an insuperable obstacle to the adoption of Prout's original view, and subsequently attempts were made to fit the numbers which resulted from more and more accurate experiment to a unit assumed to be first one-half, and subsequently one-fourth, of the atomic weight of hydrogen. Prout's hypothesis has been revived from time to time, but the progress of research has shown that in its original form, at any rate, the hypothesis is based on an illusion.

But though a comprehensive scheme was not possible the recognition of families of closely allied elements led to much study of the numerical relations among their atomic weights. Among the elements first to attract notice were the halogens—chlorine, bromine, and iodine ; the sulphur group—sulphur, selenion, and tellurium ; and the

ATOMIC WEIGHTS

alkali metals—potassium, sodium, and lithium. The nature of the relation observed will be sufficiently indicated by one case.

Adopting the atomic weights that are used by Doebereiner in his memoir* for sulphur 32·239, selenion 79·263, and tellurium 129·243, it can be shown that these conform very nearly to an arithmetical progression, for

$$\frac{32\cdot239 + 129\cdot243}{2} = 80\cdot741$$

In other words, the atomic weight of selenion, which in properties stands between sulphur and tellurium, is very nearly the arithmetic mean of the atomic weights of the other two elements.

The next step in advance is represented by the various attempts to establish an analogy between series of related elements and groups of carbon compounds, which about 1848 began to be arranged in “homo-

* “Versuche zu einer Gruppierung der elementaren Stoffe nach ihrer Analogie.” *Pogg. Ann.* (1829) 15, 301.

THE ELEMENTS

logous " series. Such a series consists of compounds of the same type containing, in addition to carbon, the same elements, exhibiting the same chemical characteristics, but differing from one another in molecular weight, and hence in physical properties.

The composition of such a series is expressible by a general formula in which, passing from any one term to the next above or below, there is a uniform difference of one atom of carbon and two atoms of hydrogen, or CH_2 . An example will render this quite clear.

The normal primary alcohols.

Name.	Formula $\text{C}_n\text{H}_{2n+2}\text{O}$.	Molecular weight.	Boiling point.
Methylic	. CH_4O	32	66°
Ethylic	. $\text{C}_2\text{H}_6\text{O}$	46	78.3°
Propylic	. $\text{C}_3\text{H}_8\text{O}$	60	97.4°
Butylic	. $\text{C}_4\text{H}_{10}\text{O}$	74	116.8°
Amylic	. $\text{C}_5\text{H}_{12}\text{O}$	88	137°
Hexylic	. $\text{C}_6\text{H}_{14}\text{O}$	102	157°
Heptylic	. $\text{C}_7\text{H}_{16}\text{O}$	116	175°
etc.	etc.	etc.	etc.

ATOMIC WEIGHTS

These are all compounds containing one atom of oxygen in the form of hydroxyl, HO, while the carbon and hydrogen increase by successive additions of CH₂, and this increase is accompanied by a fairly steady rise in the boiling point, increase of specific gravity, and gradual change in viscosity till, in the highest terms not given in the table, the alcohol becomes a crystalline solid at common temperatures.

Selecting any three successive terms the molecular weights show the same kind of relation, though with greater numerical exactitude, as that which is observed among the atomic weights in a natural family of elements.

For example :

$$\frac{\text{Amylic} + \text{Heptylic Alcohol}}{2} = \frac{88 + 116}{2} = \text{Hexylic Al. } 102$$

This is parallel with the relation existing among the alkali metals :

$$\frac{\text{Lithium} + \text{Potassium}}{2} = \frac{7 + 39\cdot1}{2} = \text{Sodium } 23\cdot0$$

THE ELEMENTS

The formula of the alcohols may be written $\text{H}_2\text{O} + n\text{CH}_2$, and by giving to n any desired value the formula of any term of the series may be arrived at.

Similarly the atomic weights of the elements composing a natural family may be calculated by adopting the atomic weight of the first term as the basis to which additions may be made of a common increment.

Thus the alkali metals may be treated as derived from the basis 7, with differences equal to $n16$, so that a being the value of the basis, $a + nd$ gives the atomic weight.

$$a = 7 = \text{Lithium}$$

$$a + d = 7 + 16 = 23 = \text{Sodium}$$

$$a + 2d = 7 + 32 = 39 = \text{Potassium}$$

In some cases it is necessary to assume two values for the increment, as in the case of the halogens and several other groups. Thus for the halogens :

$$a = 19 = \text{Fluorine}$$

$$a + d = 19 + 16.5 = 35.5 = \text{Chlorine}$$

$$a + 2d + d' = 19 + 33 + 28 = 80 = \text{Bromine}$$

$$2a + 2d + 2d' = 38 + 33 + 56 = 127 = \text{Iodine}$$

ATOMIC WEIGHTS

Several attempts in this direction were made in the middle of the nineteenth century, and of these the memoir of Dumas* represents perhaps the most determined and comprehensive.

It is unquestionably true that something akin to homology is to be traced in many families of elements, but at present in no case has a satisfactory formula been discovered for the calculation of the atomic weights so as to bring them into harmony with the values deduced from the most exact experiments.†

The arrangement of the elements in groups consisting of closely allied members does not, however, provide the clue to a scheme by which the whole of the elements could be shown to belong to one system of things. Prout's hypothesis seems to have been the only attempt to provide a general

* "Mémoire sur les Équiv. des Corps Simples." *Ann. Chim. Phys.* [3], iv, 129.

† See, however, later, chapter iv.

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law up to a period which commences about 1860-62. As already mentioned, this is attributable to two causes, namely, first the want of knowledge about the chemical characters of a considerable number of the elements; and secondly, the want of co-ordination among the atomic weights.

Of the chemists to whom the study of this question appealed strongly Odling should first be mentioned. Having occupied himself with the relations traceable among atomic weights from 1857 onward, Odling published, in 1864, an article containing a table in which the atomic weights of forty-five of the best-known elements are arranged horizontally in the order of their generally received groups, and perpendicularly in the order of their several atomic weights (*Watts's Dict.*, iii, 975).

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			Mo 96 — — Pd 106.5	W 184 Au 196.5 Pt 197
Li 7	Na 23	—	Ag 108	—
G 9	Mg 24	Zn 65	Cd 112	Hg 200
B 11	Al 27.5	—	—	Tl 203
C 12	Si 28	—	Sn 118	Pb 207
N 14	P 31	As 75	Sb 122	Bi 210
O 16	S 32	Se 79.5	Te 129	—
F 19	Cl 35.5	Br 80	I 127	—
	K 39	Rb 85	Cs 133	—
	Ca 40	Sr 87.5	Ba 137	—
	Ti 48	Zr 89.5	—	Th 231
	Cr 52.5	—	V 138	—
	Mn 55 etc.	—	—	—

Here chromium and manganese are supposed to represent the metals of the iron group, and palladium and platinum their respective congeners, so that the total number of elements provided for amounts to about fifty-two. It will be seen later that this table embodies a scheme which is only one step removed from the presentation of the periodic law which has since become the commonly accepted basis of classification.

In the meantime other chemists and physicists were at work on the problem, and

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in order that as far as possible justice may be done to the several publications which ensued, mention must be made of some of them.

In 1862 Beguyer de Chancourtois,* a French geologist, conceived the idea of representing geometrically the relations among the atomic weights of the then known elements by the device of a spiral drawn upon the surface of a cylinder with circular base divided into sixteen equal parts, the spiral cutting the generatrices (vertical lines) of the cylinder at an angle of 45° . By measuring off from the base lengths corresponding to what he called "the characteristic numbers," that is the atomic weights, de Chancourtois showed that elements of similar character often found places on the same generating line. Thus oxygen, sulphur, selenion, and tellurium stand vertically above one another, as also do the members of several other natural families, though intermingled with others not related to them.

* *Comptes Rendus*, 1862 and 1863.

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But the language of the memoir is so obscure that it is uncertain whether the author really recognised the general relationship of properties to atomic weight.* At one time he seems to be discussing the distribution of the elements in minerals, and at another to be confused by the fact that the atomic weights are not whole numbers, and the differences between them are not constant, and therefore cannot exhibit simple geometrical relationships on his "*Vis tellurique*," or telluric helix.

Among other early attempts to trace a law of general application the several papers

* The following passage extracted from one of his memoirs sufficiently explains his position:—

"La proposition fondamentale de mon système: *Les rapports des propriétés des corps sont manifestés par des rapports simples de position de leurs points caractéristiques.* Par exemple, l'oxygène, le soufre, le sélénium, le tellure, le bismuth, s'alignent sensiblement sur une génératrice, tandis que le magnésium, le calcium, le fer, le strontium, l'urane, le barium s'alignent sur une génératrice opposée; à côté de la première figurent d'une part l'hydrogène et le zinc, d'autre part le brome et l'iode, le cuivre et le plomb; à côté de la deuxième s'alignent le lithium, le sodium, le potassium et le manganèse, etc. etc." *Comptes Rendus*, 54 (1862), 758.

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of J. A. R. Newlands claim the most attention, for this chemist was the first to draw attention *definitely* to the periodic character of the relation which is observable among the majority of the elements when a list is drawn up in the order of the numerical value of their atomic weights. Newlands' first paper (*Chem. News*, Feb., 1863), and several succeeding papers, treat of the relations among the equivalents, and as at this time the relation of the atomic weights to the equivalents was still undetermined by any uniform rule, the research was not always successful.

In a communication made to the Chemical Society, in March, 1866, the author adopted Cannizzaro's system, and was thereby led to revise some of his previous statements, and succeeded in enunciating on a more satisfactory basis the " Law of Octaves " which he had formulated two years previously (Aug., 1864).

His own words were as follows : " If the

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elements are arranged in the order of their equivalents, calling hydrogen 1, lithium 2, glucinum 3, boron 4, and so on (a separate number being attached to each element having a distinct equivalent of its own, and where two elements happen to have the same equivalent, both being designated by the same number) it will be observed that elements having consecutive numbers frequently either belong to the same group or occupy similar positions in different groups." And referring to a tabular arrangement of some of the elements he proceeded: "Here the difference between the number of the lowest member of a group and that immediately above it is 7; in other words, the eighth element starting from a given one is a kind of repetition of the first, like the eighth note of an octave in music."

The following table was given later, when corrected atomic weights had been adopted.

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ELEMENTS ARRANGED IN OCTAVES

No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
H 1	F 8	Cl 15	Co & Ni 22	Br 29	Pd 36	I 42	Pt & Ir 50		
Li 2	Na 9	K 16	Cu 23	Rb 30	Ag 37	Cs 44	Os 51		
G 3	Mg 10	Ca 17	Zn 24	Sr 31	Cd 38	Ba & V 45	Hg 52		
Bo 4	Al 11	Cr 18	Y 25	Ce & La 32	U 39	Ta 46	Tl 53		
C 5	Si 12	Ti 19	In 26	Zr 33	Sn 40	W 47	Pb 54		
N 6	P 13	Mn 20	As 27	Di & Mo 34	Sb 41	Nb 48	Bi 55		
O 7	S 14	Fe 21	Se 28	Ro & Ru 35	Te 43	Au 49	Th 56		

(*Chem. News*, March 9, 1866.)

At the meeting of the Chemical Society, when this table was brought forward, the objection was raised by Dr. Gladstone that no provision is made for elements which remained to be discovered. As the previous few years had brought forth cæsium, rubidium, thallium, and indium there was considerable force in the remark, and to this curious mistake on the part of the author may be partly attributed the fact that he was not more successful in sustaining his fundamental idea. Nevertheless it must be admitted that Newlands was the first to announce definitely the discovery that the properties of the elements are a periodic function of their atomic weights, and this is clearly stated in his enunciation of his law

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of octaves, and is obvious from the positions assigned to a majority of the elements in the table. Unfortunately, he appears to have appreciated very imperfectly the importance of the principle involved, and he wrote no more on the subject till 1872, after the publication of Mendeléeff's famous memoir, of which an account will now be given.

From what has gone before it is obvious that the way was being prepared for a generalisation concerning the relation of properties to atomic weight, and it was therefore natural that Professor Mendeléeff, being occupied in the compilation of his well-known work entitled, in the English translation, *The Principles of Chemistry*, should have his attention strongly attracted to the subject.

In March, 1869, Mendeléeff communicated to the Russian Chemical Society a memoir, of which an abstract only appeared, in German (*Zeitsch. f. Chem.*, v, 405), and of which the following is a translation, slightly

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abbreviated, several obvious misprints being corrected, as well as one important error of translation, the Russian word for periodic having been rendered by the German "stufenweise," or gradual.

"When the elements are arranged in vertical columns, according to increasing atomic weight, so that the horizontal lines contain analogous elements, again according to increasing atomic weight, the following arrangement results, from which several general conclusions may be derived :

			Ti= 50	Zr = 90	? =180
			V = 51	Nb = 94	Ta =182
			Cr= 52	Mo = 96	W =186
			Mn= 55	Rh =104.4	Pt =197.4
			Fe= 56	Ru =104.4	Ir =198
		Ni=Co= 59	Pd =106.6	Os =199	
H =1			Cu= 63.4	Ag =108	Hg=200
	Be = 9.4	Mg=24	Zn= 65.2	Cd =112	
	B =11	Al =27.4	? = 68	Ur =116	Au =197?
	C =12	Si =28	? = 70	Sn =118	
	N =14	P =31	As= 75	Sb =122	Bi =210?
	O =16	S =32	Se =79.4	Te =128?	
	F =19	Cl =35.5	Br= 80	I =127	
Li=7	Na=23	K =39	Rb= 85.4	Cs =133	Tl =204
		Ca =40	Sr= 87.6	Ba =137	Pb =207
		=45	Ce= 92		
		Er=56	La= 94		
		Yt=60	Di= 95		
		? In =75.6	Th=118		

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“ 1. The elements according to the magnitude of atomic weight show a periodic change of properties.

“ 2. Chemically analogous elements have atomic weights either in agreement (Pt, Ir, Os), or increasing by equal amounts (K, Rb, Cs).

“ 3. The arrangement according to atomic weights corresponds with the valency of the elements, and to a certain extent the difference in chemical behaviour, for example, Li, Be, B, C, N, O, F.

“ 4. The elements most widely distributed in nature have small atomic weights, and all such elements are distinguished by their characteristic behaviour. They are thus *typical* elements and the lightest element, hydrogen, is therefore rightly chosen as the typical unit of mass.

“ 5. The magnitude of the atomic weight determines the properties of the element. Hence the compounds of S and Te, of Cl and I show, beside many analogies, striking differences.

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“ 6. It allows the discovery of many *new* elements to be foreseen; for example, analogues of Si and Al with atomic weights between 65 and 75.

“ 7. Some atomic weights will experience correction; for example, Te cannot have the atomic weight 128, but 123 to 126.”

From the foregoing table the principle of periodicity, that is, recurrence of similar properties at regular intervals with increase of atomic weight, is less obvious than it afterwards became when, in 1871, the arrangement was modified so as to assume the form now commonly adopted in text-books of chemistry.

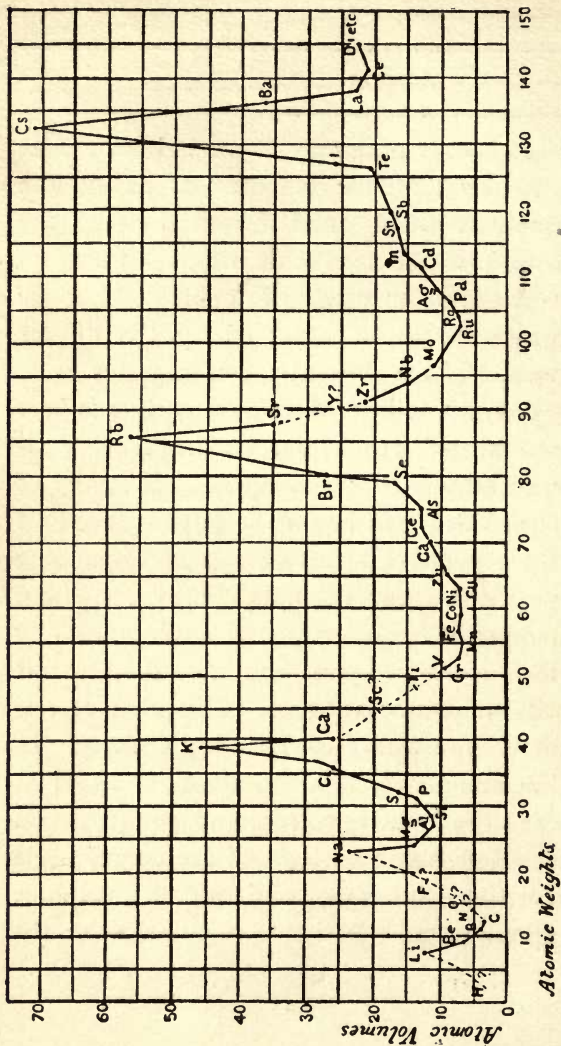
In the meantime the study of the question led the German Professor Lothar Meyer to conclusions practically identical with those of Mendeléeff, and by his famous diagram of atomic volumes to illustrate very clearly the periodic recurrence of many of the physical properties of the elements when arranged in the order of atomic weights.

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It is only necessary to remind the reader that by "atomic volume" is meant the quotient which results from dividing the atomic weight by the density. It therefore represents the volume in cubic centimetres which would be occupied by the atomic weight of the element taken in grams.

Meyer's table,* of which a portion is here reproduced, speaks for itself. Tracing almost any well recognised natural family of elements, it can be seen from the curve that the successive terms occupy corresponding positions. For example, lithium, sodium, potassium, rubidium, and cæsium occupy the successive apices and have the greatest known atomic volumes. This character is associated with great chemical activity. In like manner calcium, strontium, and barium are to be found in corresponding positions on the descending portions of the curve, while chlorine, bromine, and iodine, sulphur, selenion, and tellurium occupy places on the

* *Annalen* (Dec., 1869). Supplement, p. 354.



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ascending portions. Other properties and relations are similarly recognisable.

Nevertheless, Mendeléeff is rightly regarded as the discoverer of the law. His title to be so regarded is based on the fact that he not only proclaimed the law afresh, and apparently in ignorance of Newlands' work, but he displayed that deep conviction of its important consequences which led him to some of the most striking and interesting of its applications. A detailed account of many of these is to be found in all the best textbooks of chemistry; it is unnecessary, therefore, to do more than to indicate by a single example the application of the principle, which is embodied in Mendeléeff's revised table, to the prediction of new elements and a prevision of their physical and chemical properties.

The table, in its latest form, as arranged by Mendeléeff, in 1904, to include all the known elements except the "rare earths," is shown below.

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Series.	Zero group.	Group I.	Group II.	Group III.	Group IV.
0 ..	<i>x</i>	—	—	—	—
1 ..	<i>y</i>	Hydrogen, H=1·008	—	—	—
2 ..	Helium, He=4·0	Lithium, Li=7·03	Beryllium, Be=9·1	Boron, B=11·0	Carbon, C=12·0
3 ..	Neon, Ne=19·9	Sodium, Na=23·05	Magnesium, Mg=24·1	Aluminium, Al=27·0	Silicon, Si=28·4
4 ..	Argon, Ar=38	Potassium, K=39·1	Calcium, Ca=40·1	Scandium, Sc=44·1	Titanium, ✓ Ti=48·1
5 ..	—	Copper, · Cu=63·6	Zinc, Zn=65·4	Gallium, Ga=70·0	Germanium, Ge=72·3
6 ..	Krypton, Kr=81·8	Rubidium, Rb=85·4	Strontium, Sr=87·6	Yttrium, Y=89·0	Zirconium, Zr=90·6
7 ..	—	Silver, Ag=107·9	Cadmium, Cd=112·4	Indium, In=114·0	Tin, · Sn=119·0
8 ..	Xenon, Xe=128	Cæsium, Cs=132·9	Barium, Ba=137·4	Lanthanum, La=139	Cerium, Ce=140
9 ..	—	—	—	—	—
10 ..	—	—	—	Ytterbium, Yb=173	—
11 ..	—	Gold, Au=197·2	Mercury, Hg=200·0	Thallium, Tl=204·1	Lead, · Pb=206·9
12 ..	—	—	Radium, Rd=224	—	Thorium, Th=232

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Group V.	Group VI.	Group VII. 	Group VIII.		
—	—	—	—	—	—
—	—	—	—	—	—
Nitrogen, N=14.04	Oxygen, O=16.0	Fluorine, F=19.0	—	—	—
Phosphorus P=31.0	Sulphur, S=32.06	Chlorine, Cl=35.45	—	—	—
Vanadium, V=51.4	Chromium, Cr=52.1	Manganese, Mn=55.0	Iron, Fe=55.9	Cobalt, Co=59	Nickel, Ni=59 (Cu)
Arsenic, As=75.0	Selenium, Se=79.0	Bromine, Br=79.95	—	—	—
Niobium, Nb=94.0	Molybdenum Mo=96.0	—	Ruthenium, Rhodium, Palladium. Ru=101.7 Rh=103.0 Pd=106.5 (Ag)		
Antimony, Sb=120.0	Tellurium, Te=127	Iodine, I=127	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
Tantalum, Ta=183.0	Tungsten, W=184	—	Osmium, Os=191	Iridium, Ir=193	Platinum, Pt=194.9 (Au)
Bismuth, Bi=208	—	—	—	—	—
—	Uranium, U=239	—	—	—	—

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In 1871, when Mendeléeff drew up this table, the spaces corresponding to atomic weights 44, 70, and 72 were vacant. To the hypothetical elements expected to occupy these positions he gave the names ekaboron, akaluminium, and ekasilicon, and to each he assigned the properties which were soon afterwards recognised in the new elements scandium (at. wt. 44), gallium (at. wt. 69.9), and germanium (at. wt. 72.5).

To the element standing next after zinc Mendeléeff gave the name eka-aluminium, and the following is the outline he gave of its properties :* “ It will be in the same group as Al, and should consequently give R_2O_3 , RCl_3 , $R_2(SO_4)_3$, alums, and like compounds analogous to those of aluminium. Its oxide should be more easily reducible to metal than alumina, just as zinc oxide is more easily reduced than magnesia. The oxide R_2O_3 should, like alumina, have feeble but clearly expressed basic properties. The

* *Principles*, ii, 84 (Engl. ed., 1891).

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metal reduced from its compounds should have a greater atomic volume than zinc, because in the fifth series, proceeding from zinc to bromine, the volume increases. And as the volume of zinc is 9.2, and of arsenic 18, therefore that of our metal should be near to 12. This is also evident from the fact that the volume of aluminium = 11, and of indium = 14, and our metal is situated in the III group, between aluminium and indium.

If its volume is 11.5 and its atomic weight be about 69, then its density will be nearly 5.9. The fact of zinc being more volatile than magnesium gives reason for thinking that the metal in question will be more volatile than aluminium, and therefore for expecting its discovery by the aid of the spectroscope, etc."

In 1875 Lecoq de Boisbaudran discovered by means of the spectroscope a new metal in a zinc blende from the Pyrenees. This he named gallium, and it was found by subsequent study to have the atomic weight 69.8,

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the density 5.9, to form a sesquioxide Ga_2O_3 , and an octahedral alum, like common alum. The metal is soluble in acids and in alkaline hydroxide, and possesses many of the properties of aluminium. It is, however, much more fusible, melting at 30° ; just as zinc is more fusible than magnesium.

Similar predictions concerning the other two hypothetical elements mentioned above were completely confirmed by the properties observed in the metals scandium and germanium. No justification could be more complete, and Mendeléeff's scheme has continued to furnish the guiding principle of the greater part of modern inorganic chemical research.

CHAPTER III

THE PERIODIC LAW

“As in Mathematics so in Natural Philosophy, the investigation of difficult things by the method of analysis ought ever to precede the method of composition.”

NEWTON, *Opticks*.

HAVING traced the gradual course of development of the idea which is embodied in Mendeléeff's scheme of the elements it will now be useful to examine more closely his statement of the “Periodic Law.” Mendeléeff's own words rendered into English in the latest edition of his *Principles* (1905, vol. ii, p. 17) appear as follows: “The properties of the elements, as well as the forms and properties of their compounds, are in periodic dependence on, or (expressing ourselves algebraically) form a periodic function of, the atomic weights of the elements.”

In order that the question of the general

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validity of this law may be fairly considered it is necessary first of all to inquire whether there is any reason to expect the discovery, by further research, of substances of elemental character at present unrecognised. In order to answer this question the first thing to do is to examine the list of elements now generally acknowledged, and it will be found that they form a continuous series, with a roughly uniform progression in the value of the atomic weight in passing from term to term. The following table contains the names and atomic weights of the eighty-one elements recognised by the International Committee on Atomic Weights with the numerical values adopted by that body.

ELEMENTS

ARRANGED IN ORDER ACCORDING TO
ATOMIC WEIGHT

Hydrogen . . .	1.008	Nitrogen . . .	14.01
Helium . . .	4.0	Oxygen . . .	16.00
Lithium . . .	7.00	Fluorine . . .	19.0
Beryllium (Glucinum) . . .	9.1	Neon . . .	20.0
Boron . . .	11.0	Sodium . . .	23.00
Carbon . . .	12.00	Magnesium . . .	24.32

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Aluminium . . .	27·1	Indium . . .	114·8
Silicon . . .	28·3	Tin . . .	119·0
Phosphorus . . .	31·0	Antimony . . .	120·2
Sulphur . . .	32·07	*Tellurium . . .	127·5
Chlorine . . .	35·46	Iodine . . .	126·92
*Argon . . .	39·9	Xenon . . .	130·7
Potassium . . .	39·10	Cæsium . . .	132·81
Calcium . . .	40·09	Barium . . .	137·37
Scandium . . .	44·1	Lanthanum . . .	139·0
Titanium . . .	48·1	Cerium . . .	140·25
Vanadium . . .	51·2	Praseodymium . . .	140·6
Chromium . . .	52·0	Neodymium . . .	144·3
Manganese . . .	54·93	Samarium . . .	150·4
Iron . . .	55·85	Europium . . .	152·0
Nickel . . .	58·68	Gadolinium . . .	157·3
Cobalt . . .	58·97	Terbium . . .	159·2
Copper . . .	63·57	Dysprosium . . .	162·5
Zinc . . .	65·37	Erbium . . .	167·4
Gallium . . .	69·9	Thulium . . .	168·5
Germanium . . .	72·5	Ytterbium . . .	172·0
Arsenic . . .	74·96	Lutecium . . .	174·0
Selenium . . .	79·2	Tantalum . . .	181·0
Bromine . . .	79·92	Tungsten . . .	184·0
Krypton . . .	83·0	Osmium . . .	190·9
Rubidium . . .	85·45	Iridium . . .	193·1
Strontium . . .	87·62	Platinum . . .	195·0
Yttrium . . .	89·0	Gold . . .	197·2
Zirconium . . .	90·6	Mercury . . .	200·0
Niobium(Columbium) . . .	93·5	Thallium . . .	204·0
Molybdenum . . .	96·0	Lead . . .	207·10
Ruthenium . . .	101·7	Bismuth . . .	208·0
Rhodium . . .	102·9	Radium . . .	226·4
Palladium . . .	106·7	Thorium . . .	232·42
Silver . . .	107·88	Uranium . . .	238·5
Cadmium . . .	112·40	(Total 81.)	

* Argon and tellurium are placed out of numerical order on account of the uncertainty still attaching to the relative values of their atomic weights and those of the elements immediately following them.

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It will be observed that in passing from one element to the next in the list the differences between the atomic weights vary from 0.29 (Co - Ni) to 4.6 (Cu - Co), among the elements of which the atomic weights are not very large and most of which have been determined with considerable approach to accuracy.

The relatively large difference, 7.3, between antimony and tellurium is attributed to some error in the atomic weight of tellurium, of which no sufficient explanation has yet been found ; but there is a gap between molybdenum and ruthenium amounting to 5.7 units, which is supposed to indicate a vacancy appropriated in the Mendeléeff scheme to a homologue of manganese. The atomic weights of the fourteen elements, beginning with lanthanum, are confessedly uncertain, but that they all lie between lanthanum and tantalum seems probable, because, although the individual numbers are doubtless inexact, the average difference

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between any two consecutive terms is approximately the same as the average difference between successive atomic weights among the better known elements preceding them. $Ta - La = 181 - 139 = 42$ for thirteen intervals, or about 3.2.

Between tungsten and osmium a difference of 6.9 units seems to indicate something missing, and from bismuth, 208, to radium, 226.4, there is a wide interval which seems to indicate about four vacant places. It is, of course, uncertain whether the same order of increase is to be expected in the larger numbers, and whether some irregularity is possible or even probable here.

It should also be noted that the differences, approximately three units each, among the three elements with smallest known atomic weights, namely :

H 1.008 He 4.0 Li 7.00

are greater than the differences observed

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among the elements immediately following them, namely :

Li 7.00 Be 9.1 B 11.0 C 12.00 N 14.01
O 16.00 F 19.0 Ne 20.0

which show an average difference of less than two units between successive terms.

At present no element is known with a smaller atomic weight than hydrogen or a larger atomic weight than uranium. Remembering that the "atomic weights" are only ratios and represent only the *relative* magnitude of the masses of the atoms, and not their *absolute* masses in terms of any standard, there is nothing in theory to preclude the expectation of additions of new substances to either extremity of the series. However, the spectroscopic simplicity of hydrogen seems to hint that its constitution is near the limit at one end, and the belief that radio-activity is occasioned by the instability of the larger atoms at the other end leads to the suspicion, if not the convic-

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tion, that the series is limited by this instability, which, so far as is at present known, is associated with an atomic weight approximating to 240.

From this point of view, then, the total number of new elements to be expected is not large, and they are for the most part such as would exhibit metallic characters and a high atomic weight.

The significance of these differences among the successive atomic weights is more easily recognised when the elements are arranged in such a table as that of Mendeléeff (p. 46), where their natural affinities are brought into view and a number of natural families can be at once selected, each possessing well-marked characters common to the whole family. The most strongly marked of these families are the following :

1. Helium, neon, argon, krypton, xenon.
2. Lithium, sodium, potassium, rubidium, cæsium.

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3. Beryllium, magnesium, zinc, cadmium, mercury.
4. Calcium, strontium, barium, radium.
5. Aluminium, gallium, indium.
6. Silicon, titanium, zirconium.
7. Germanium, tin, lead.
8. Nitrogen, phosphorus, arsenic, antimony, bismuth.
9. Vanadium, niobium, tantalum.
10. Oxygen, sulphur, selenium, tellurium.
11. Fluorine, chlorine, bromine, iodine.
12. Chromium, manganese, cobalt, iron, nickel, copper.
13. Chromium, molybdenum, tungsten, and uranium.
14. Ruthenium, rhodium, palladium, osmium, iridium, platinum.

Here it may be to the advantage of the reader if a sketch is given of the characters by which one or two of these families are distinguished, in order to indicate the sort of features which are regarded as important in determining relationships. These are

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at once divisible into two kinds, namely, (1) those which are recognised as matters of fact, such as the physical and chemical properties of the elements and of their chief compounds; and (2) valency, which is to some extent involved in theory.

Concerning the former it will be found in all cases that density, fusibility, or volatility, and chemical activity are obviously related to atomic weight, the density always increasing with increasing atomic weight, while volatility generally diminishes among the non-metals, and increases among the metals with rise in the value of atomic weight.

As to valency, or the capacity displayed by the atom of the element to associate with other atoms, if used alone this character would bring together quite incongruous materials, while it sometimes separates very similar substances. Phosphorus and sulphur, for example, are very much alike, as are also antimony and tellurium and other elements, which are properly placed in separate

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families in consideration of their differences of valency.

The alkali metals may be taken as an example. These substances are silvery white, very fusible, volatile solids, which communicate to flame characteristic colours, those given by potassium, rubidium, and caesium being purplish and almost indistinguishable from each other by the eye. By means of the spectroscope these lights are resolvable into a very small number of bright lines. These metals decompose water violently and are distinguished by their tendency to unite with oxygen, their electro-positive character increasing as the atomic weight increases. Their salts are with very few exceptions easily soluble in water, and the corresponding salts are usually isomorphous. Thus the chlorides, bromides, and iodides, when anhydrous, crystallise in cubes, and the sulphates, with the exception of lithium sulphate, unite with aluminium sulphate and water to form alums which

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crystallise in regular octahedrons. Their chief physical properties are shown in the following table :

	Li	Na	K	Rb	Cs
Atomic Wt.	7.0	23.0	39.1	85.45	132.81
Density	0.59	0.97	0.87	1.52	1.88
Atomic Vol.	11.9	23.6	44.9	56.2	70.6
Melting Pt.	186°	95°	62°	38.5°	26°
Boiling Pt.	above red	742°	667°	?	?

These elements are all univalent, that is, one atom of the metal is capable of combining with or of displacing one atom of hydrogen, and there is no well recognised evidence that they ever show a greater capacity for combination.

Turning now to the opposite side of the table, the halogens may be taken as an example of a well-defined natural family.

These are all very volatile substances, the vapours of which exhibit characteristic colours ; fluorine pale yellow, chlorine greenish yellow, bromine orange-red, iodine deep purple. By reason of their low boiling points fluorine and chlorine are gaseous at atmospheric pressure and temperature, while bromine is a red dense liquid, and iodine a

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black, lustrous, crystalline solid. They are distinguished by the tendency they exhibit to combine with hydrogen and metals, and not, by any direct process, with oxygen. Fluorine is the most electro-negative element known, displacing chlorine from the chlorides and entering into combination with hydrogen even in the dark and at very low temperatures. It seems to be incapable of combining with oxygen under any circumstances. The following table exhibits the chief physical properties of these elements, and as in the case of the metals it may be noticed that these properties follow the numerical magnitude of the atomic weight, the chemical activity standing in the inverse order, fluorine being the most active, while iodine is the least.

	F	Cl	Br	I
Atomic Wt. . . .	19.0	35.46	79.92	126.92
Density gas (H=1) . .	19	35.5	80	127
,, liquid	1.14 (at -200°)	1.42	3.18	—
,, or solid	.	.	.	4.9
Atomic Vol. . . .	16.6	25.0	25.1	25.7
Melting Pt. . . .	below -210°	-7° to -8°		114°
Boiling Pt. . . .				
at atmos. pressure . }	-187°	-33°	63°	184°

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In this family, as in many others, the first and last members of the series exhibit abnormalities, but it is unnecessary in this place to enter into details regarding the peculiarities of fluorine, on the one hand, and of iodine on the other.

The valency of the group in their compounds with hydrogen and the metals is habitually represented by one unit; but in certain compounds, notably in those which contain oxygen, it is necessary to assume a higher degree of combining capacity, amounting to three, or, according to some chemists, five or even seven, units.

✓ If the table of elements drawn up by Mendeléeff is now inspected it becomes at once obvious that, after Series I, of which hydrogen is the only acknowledged member, the two following lines illustrate perfectly the principle of periodicity. Here the ninth element, counting from the first, exhibits an almost perfect reproduction of the same assemblage of properties as the first with such modification as might be

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expected from the increase of density which follows the increase of atomic weight. The fourth series, however, shows greater differences, first in respect to the positions assigned to chromium and manganese respectively, which in their metallic character are wholly unlike the sulphur and halogen groups to which they are attached ; and secondly, in the fact that the atomic weights of iron, nickel, and cobalt bring these elements into close association with manganese and to provide places for them it is necessary to assume an extension of the period by the addition of an eighth group. Admitting this modification, the characteristics of these metals should be revived later on among elements of higher atomic weight. The platinum metals do in two series represent correlatives of the iron group which they resemble in difficult fusibility, in the tendency to occlude hydrogen and in the formation of complex cyanides and ammines. Complete revival of characteristics is not to be looked for, and there is considerable modification of valency.

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Passing over the difficulties encountered in respect to individual elements such as those already mentioned and others, the most serious problem is presented by the elements related to cerium, and constituting the substances long known as the "rare earths." Thirteen of these substances are recognised by the Atomic Weight Committee, and will be found in the table of atomic weights, commencing with lanthanum, 139, and ending with lutecium, 174.

These metals form sesquioxides, and their sulphates constitute an isomorphous group, with the general formula $R_2(SO_4)_3 \cdot 8H_2O$. Some of them have been reduced to the metallic state and their densities have been found to approximate to the density of iron, but with much lower melting-point.

	Dens.	M.P.*
Cerium . . .	7.04	623°
Lanthanum . . .	6.15	810°
Praseodymium . . .	6.47	940°
Neodymium . . .	6.96	840°
Samarium . . .	7.75	—
(Iron)	7.84	above 1600°

* Muthmann and Weiss, *Annalen*, 1904, 331, 1.

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Two kinds of difficulty arise in connection with the placing of these metals in the scheme. They are all usually trivalent, forming sesquioxides, and therefore cannot fall into successive groups with different valencies, and they are much less easily reducible than the platinum metals ; and in respect to density they do not fall between the two subdivisions of those metals, the lighter with density about 12, and the heavier with density 21-22, shown in Group VIII.

Mendeléeff's enunciation of the periodic principle, therefore, can only be accepted with some qualification.

An inspection of the table shows that following Series 3 there is an obvious division of each group vertically into two sub-groups, one of which preserves, substantially, the character of the type ; the other displays a very rapid development of quite new features. This is perhaps best shown by tabulating the former separately, as follows :

Series.	Zero.	Group I.	Group II.	Group III.	Group IV.	Group V.	Group VI.	Group VII.
1	—	H 1'0	—	—	—	—	—	—
2	He 4	Li 7	Be 9'1	Bo 11	C 12	N 14	O 16	F 19
3	Ne 20	Na 23	Mg 24'3	Al 27'1	Si 28'3	P 31	S 32	Cl 35'4
4	A 39'9	K 39'1	Ca 40	Sc 44'1	Ti 48'1	—	—	—
5	—	—	—	—	—	As 74'9	Se 79'2	Br 79'9
6	Kr 83	Rb 85'4	Sr 87'6	Y 89	Zr 90'6	—	—	—
7	—	—	—	—	—	Sb 120'2	Te 127'5	I 126'9
8	Xe 130'7	Cs 132'8	Ba 137'3	La 139	Ce 140'2	—	—	—
9	—	—	—	—	—	—	—	—
10	—	—	—	—	—	—	—	—
11	—	—	—	—	—	Bi 208	—	—
12	—	—	? Ra 226	—	Th 232'4	—	—	—

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Here it will be perceived that as atomic weight increases in each vertical column there is a tendency to increase in the electro-positive character of the element, indicated among the metals by the greater difficulty encountered in the isolation of the metal from its compounds and in the more strongly marked basic character of the oxides. Among the non-metals the increase of atomic weight in any group is attended by gradual development of metalloidal characters, as may be noticed in passing from phosphorus to antimony, from sulphur to tellurium, and from chlorine to iodine.

The elements omitted are all metallic in character, and, as with the rest, their metallic qualities in each group suffer modification, but in the inverse order, for reduction to the metallic state is here generally easier among the elements of highest atomic weight, and the basic properties of the oxides are most strongly marked among those of lower atomic weight. This may be recognised in

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following the successive members of such a family as copper, silver, gold, or zinc, cadmium, mercury ; or by comparison of the iron group with the two sub-groups of platinum metals.

The elements referred to are arranged in their several groups and series in the following table. (See next page.)

[illegible]

CHAPTER IV

THEORIES OF EVOLUTION

“WE may almost consider the *πρώτη ὕλη* of the ancients to be realised in hydrogen, an opinion, by the way, not altogether new.”

W. PROUT, *Ann. Phil.*, 6 (1815), p. 321.

7 (1816), p. 111.

MENDELÉEFF, the prophet of the periodic doctrine, was to the last strenuously opposed to any conception which involved the idea of the evolution of the chemical elements from a primordial unique form of matter. The periodic scheme of arrangement is, however, so suggestive of some process of evolution that chemists and physicists have been for many years fascinated by the inquiry how such numerical relations can be accounted for if they are not to be understood as indicating a common origin, or the operation of some genetic process.

Since the discovery of the periodic law

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several forms of hypothesis have been brought forward. Among the earlier hypotheses the most notable is associated with the name of Sir William Crookes, who, since its original presentation in 1886, has on several occasions reiterated and amplified the expression of his views.

Crookes' ideas on the "Genesis of the Elements"* are based on a revival of the hypothesis of the existence in the dawn of the universe of a primal "ur-stoff" or "protyle" consisting of an infinite number of immeasurably small particles gradually accreting out of formless mist and moving with inconceivable velocity in all directions. These fine particles are assumed to have gradually heaped themselves into masses of increasing size, by the operation of the selective process which results from the tendency of particles with approximately the same rate and kind

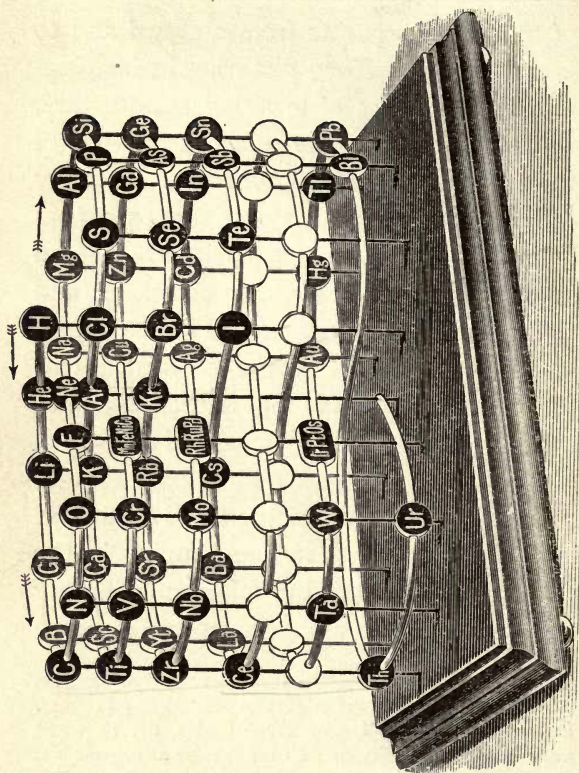
* *B.A. Report*, Birmingham, 1886. *Trans. Chem. Soc.*, 1888, Presidential Address.

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of motion to separate from a crowd and to keep together. Now, picturing in imagination the influence of lowering temperature, operating concurrently with the action of the imponderable matter or source of energy called electricity, it may be supposed that at intervals clusters of particles are formed having a more or less stable character, and that these clusters correspond to the atoms of the "elements" of the chemist. This process of evolution is represented diagrammatically by Crookes by means of a figure of eight.*

In this figure each of the loops is divided into eight equal parts, and upon it the elements are supposed to follow one another at equal distances along the spiral, a gap of

* This figure is the outcome of several modifications introduced into a diagram originally published by Professor Emerson Reynolds (*Chemical News* (1886), liv, 1), which was employed as a substitute for the tabular arrangement of Mendeléef. The diagram consisted of a zigzag curve, upon which the symbols of the elements were placed in the order of their atomic weights, and was designed to impress the idea of periodic relation of properties to atomic weight.



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one division being left at the point of crossing. "Let me suppose," he says,* "at the birth of the elements, as we now know them, the action of the *vis generatrix* might be diagrammatically represented by a journey to and fro in cycles along a figure of eight path, while simultaneously time is flowing on, and some circumstance by which the element-forming cause is conditioned (e.g. temperature) is declining (variations which I have endeavoured to represent by the downward slope). The result of the first cycle may be represented in the diagram by supposing that the unknown formative cause has scattered along its journey the groupings now called hydrogen, lithium, glucinum, boron, carbon, nitrogen, oxygen, fluorine, sodium, magnesium, aluminium, silicon, phosphorus, sulphur, and chlorine. But the swing of the pendulum is not arrested at the end of the first round. It still proceeds on its journey, and had the conditions re-

* *Proc. R. Soc.*, lxiii, 409 (1898).

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mained constant the next elementary grouping generated would again be lithium, and the original cycle would eternally reappear, producing again and again the same fourteen elements. But the conditions are not quite the same. Those represented by the two mutually rectangular horizontal components of the motion (say chemical and electrical energy) are not materially modified ; that to which the vertical component corresponds has lessened, and so, instead of lithium being repeated by lithium, the groupings which form the commencement of the second cycle are not lithium, but its lineal descendant potassium."

From this it appears that the elements represent stages in the more and more condensed and complex grouping of the same primal matter or protyle. They are not supposed to be formed in succession from one another, glucinum from lithium, boron from glucinum, and so forth.

The expression "lithium . . . lineal de-

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scendant of potassium," occurring at the close of the passage quoted above, is therefore to be understood as merely referring to the position of potassium vertically below lithium, both being formed by condensation of the same material, though the atom of potassium is not supposed to result from the previous formation of an atom of lithium, and the subsequent accretion upon it of more protyle. The fundamental idea is admirably illustrated by this diagram and model, but there are some points in both the idea and the model which present difficulty. In particular the position of hydrogen is unsatisfactory, represented, as it is, in a relation toward chlorine the same as that of lithium toward potassium, while sodium is separated from lithium and the rest of the alkali metals.

Hydrogen is unquestionably a positive element, and whenever liberated by electrolysis it appears at the cathode. Its chemical activity is considerably less than that of the alkali metals, lithium and the rest, but it is

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greater than is commonly supposed, and its inferior energy, as a chemical agent, is due largely to its gaseous condition at all common temperatures. Nevertheless, it is well known that even hydrogen gas, at common temperatures and pressures, in contact with solutions of silver nitrate precipitates metallic silver, and the system zinc, dilute sulphuric acid and hydrogen reaches a condition of equilibrium when the pressure of the hydrogen evolved by the zinc reaches a certain amount.

Of course, it is now known that Graham's dream that hydrogen in the solid form would present the features of an ordinary metal has not been fulfilled, for in the solid state hydrogen appears as a colourless mass, of low density, resembling white paraffin wax.

On the other hand, the halogens are volatile substances possessing in their ordinary state a greater degree of chemical activity than any other elements. Fluorine, especially, is a pale yellow gas, condensable

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by cold and pressure to a liquid which boils at -187° C., and at -210° is still liquid. Even when solid at a temperature of about -253° , as only 20° above the absolute zero of temperature, it explodes when mixed with liquid hydrogen at the same temperature.

The arrangement exhibited by the lemniscate spiral places fluorine vertically over the positions occupied by three clusters of metals, the first composed of manganese, iron, nickel, and cobalt, the lower two containing platinum and its congeners.

In the Mendeléeff table (p. 47) manganese alone is placed in the same column as the halogens, a position assigned to it solely on the ground of its isomorphism, in the permanganates, with chlorine in the perchlorates. Iron, cobalt, and nickel form a separate series in the eighth group.

But there is a further question which is not made clear in the paper from which the passage given above is quoted. Already, in 1891, Crookes had shown to the Electrical

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Engineers* that in an exhausted tube through which an electrical discharge is passing the stream of cathode rays near the negative pole was always negatively electrified, while the other contents of the tube were positively electrified, and he explained that "the division of the molecule into groups of electro-positive and electro-negative atoms is necessary for a consistent explanation of the genesis of the elements."

This view was illustrated by a remarkable experiment in which a silver pole was used as the cathode in a vacuum tube, a mica screen with a hole in the middle being placed in front of the silver. With a high vacuum, the poles being connected with a coil, and the silver being negative, a stream of what the author formerly described as "radiant matter" shot from the silver pole and, passing through the hole in the mica plate, impinged on the glass, producing phosphorescence. After the continuance of the discharge

* *J. Inst. Elect. Eng.*, xx, 10 (1891).

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for some time metallic silver was seen to be deposited on the mica screen in the neighbourhood of the pole. This silver was always found to be electro-positive.

Later, in 1902,* the author, reviewing these facts and others, says, "In twenty-five years one's theories may change, although the facts on which they are based remain immovable. What I then called 'radiant matter' now passes as 'electrons.' . . . Thus my early hypotheses fall into order by the substitution of one expression for the other. A chemical ion consists of a material nucleus or atom of matter constituting by far the larger portion of the mass, and a few electrons or atoms of electricity. The electrons are the same as the 'satellites' of Lord Kelvin and the 'corpuscles' or particles of J. J. Thomson."

In all his later writings Crookes makes use of the current doctrine as to the dual electrical character of the components of

* *Proc. R. Soc.*, lxix, 411.

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ordinary matter, but referring to the question as to the cause of inertia in matter, he says : * “ The electron appears only as apparent mass, by reason of its electrodynamic properties, and if we consider all forms of matter to be merely congeries of electrons, the inertia of matter would be explained without any material basis. On this view the electron would be the ‘ protyle ’ of 1886, whose different groupings cause the Genesis of the Elements.”

The question which remains obscure is whether the theory requires one kind of electron only, or two kinds of electron originally opposite in character.

A very interesting paper, entitled, “ The Evolution and Devolution of the Elements,” has been published more recently by Messrs. A. C. and A. E. Jessup.† Though the process of evolution, that is, the production of elements of high atomic weight from others

* “ Modern Views on Matter.” Address to the Congress of Applied Chemistry in Berlin, 1903.

† *Phil. Mag.* (vi), xv, 21 (1908).

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of low atomic weight, cannot be recognised in any terrestrial phenomena, these authors express the opinion, as others have done, that the operations described by Crookes in the enunciation of his hypothesis may actually be watched in progress in the stars and nebulae.

Many years ago Sir Norman Lockyer* proposed a classification of stars according to their supposed differences of temperature, and ranged certain elements in the order of their appearance in such stars. This order may be broadly represented as following the magnitude of the atomic weights. Helium, gas X, for which the name "asterium" was proposed, and hydrogen appear in the hottest; calcium and magnesium in those of somewhat lower temperature; while iron and allied metals are found only in stars of presumably more advanced age and lower temperature.

The Messieurs Jessup point out that supposing evolution to have occurred, it might

* *Proc. R. Soc.*, lxi, 204.

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proceed in one of two ways, either in the strict order of atomic weight along the horizontal lines of Mendeléeff's table as assumed in the hypothesis of Crookes, or in groups of chemically related elements, that is, down the vertical columns of the table. They prefer the latter view, chiefly on the ground that the order in which the elements appear in the nebulæ and stars is not the unbroken order of the atomic weights.

They also point out that the spectra of the earliest nebulæ consist of three lines only, corresponding to hydrogen and two unknown elements. As the nebula grows more compact two more lines appear, indicative of hydrogen and helium respectively. Consequently it is supposed that in the nebulous stage of matter there are four substances, of which hydrogen and helium only are known on the earth. They also consider it probable that except these four no other elements exist in the early nebulæ, and with this assumption they proceed to account for the

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production of all the other elements. To the two primary substances, which, in addition to hydrogen and helium, are supposed to be the parents of the rest, they give the names proto-beryllium and proto-boron, with atomic weights 1.33 and 2 respectively.

In order to provide for the development of their views as to the order in which evolution occurred they have modified the table of Mendeléeff so as to give it the form shown on page 86. Assuming that all matter was at some period in the form of corpuscles, it is supposed that the four primary elements consist of stable clusters of corpuscles which gather round themselves other corpuscles in the form of concentric rings. The authors, however, refrain from speculation as to the arrangement, but in order to account for the production of the several groups which appear in the table a process of direct evolution is imagined for the families the members of which closely resemble one another, while an indirect process is required for the rest.

[illegible]

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Thus the direct process in the first three columns is easily intelligible, but to account for the ten elements following titanium it is suggested that they are the results of some indirect process of evolution from silicon. It may be observed that the direct process leads to the formation of elements of precisely the same general character and identical valency, while the indirect process leads to the formation of elements of different valencies.

The authors also make use of the idea of possible devolution, and regarding iron, nickel, and cobalt as abnormally constituted derivatives of manganese, they consider copper, zinc, gallium, and germanium as the products of a return to more normal structure. Silver, cadmium, indium, and tin are similarly regarded as recovery products of ruthenium, rhodium, and palladium; while gold, mercury, thallium, and lead are successive recovery products from osmium, iridium, and platinum.

There is much ingenious argument in this

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paper, and the superior probability of direct over indirect evolution of the natural families so far as this principle is applied in the paper is a point of interest. But the assumption of the *four* protons is a source of difficulty, and as will be seen later is a less probable hypothesis than that of two. The authors admit the anomalies in the atomic weights of tellurium and argon, which according to all available experimental evidence are greater than those of iodine and potassium respectively. This admission, it must be remembered, however, is not in harmony with Mendeléeff's periodic law. The arrangement of the elements in the table will not commend itself to all chemists on account of the disruption of familiar associations, such as the separation of zinc from magnesium, vanadium from phosphorus, tin from the carbon group, and so forth.

In the Mendeléeff chart of the elements nothing is more striking than the gathering together of the negative elements into one

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corner of the table, fluorine, the most electro-negative element known, being at the extremity opposite to the position of lithium at the head of the most electro-positive of the metals, which are flanked by the zero group of inactive elements, helium, argon, etc. If the table were wrapped round a cylinder, the groups being vertical, this argon group would stand between positive and negative. It is noticeable that the elements exhibiting more or less well-defined metallic characters are far more numerous than those which present negative characters, and the physical properties of the latter are far more diverse. There is an unmistakable family likeness about the substances called metals which, coupled with their relatively large number, seems to indicate that this form of matter was more easily produced or was relatively more stable under the conditions of high temperature or electrical stress which probably characterised the initial stages of evolution.

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The metals are, as a rule, solid, lustrous bodies possessing relatively high conductivity for heat and electricity, together with malleability and ductility. Mercury, which is so fusible as to be liquid at common temperatures, possesses the above-mentioned characters when in the solid state. On the other hand, there are, of course, several which are deficient to some extent in one or other of the common characteristics. They all agree, however, in being deposited at the cathode when any of their compounds are submitted in the liquid state to the action of an electric current.

The non-metals comprise a miscellaneous set of substances of which the majority are distinguished by being liberated at the anode in the course of electrolysis. Several of them, however, especially carbon, are not known to be deposited electrolytically. As to their physical condition at common temperatures, some are almost infusible solids, like carbon and silicon ; some are easily

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melted, like phosphorus and sulphur ; one is a liquid—bromine—and several are gases, like nitrogen, oxygen, fluorine, chlorine.

Roughly dividing the chemically active elements into the two classes, and omitting hydrogen, we find there are fifty-two metals to thirteen non-metals. Now if the members of the several groups from I to VII be considered, reading vertically downwards, it will be found that as the atomic weight increases there is generally a tendency to an increase in the positive characters of the element ; but among the negative elements there is never an increase in the negative character. Thus there is a well-marked intensification of positive character in passing down the group potassium, rubidium, cæsium, and there is something very similar observable in the next group, calcium, strontium, barium. Sodium, copper, silver, and magnesium, zinc, cadmium, do not show a corresponding development of the positive character ; but in these cases there are

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other anomalies such as, in the latter group, fusibility and volatility increasing with atomic weight instead of the reverse as usual. On the other hand, chlorine, bromine, iodine, and sulphur, selenium, tellurium or phosphorus, arsenic, antimony, exhibit in each group a tendency to the suppression of the negative or chlorous character, and even to the development of metallic appearance and basic properties, as the atomic weight is increased.

Berzelius, a century ago, attempted to explain the relative positions of the elements in an electro-chemical series by the assumption that each atom carries charges of positive and negative electricity, the preponderance of one or the other serving to determine the chemical character of the substance.

In more recent times the idea of the co-existence of two elementary principles in the atoms of the chemical "elements" has been discussed more than once.

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Carnelly, in 1885 (*Brit. Assoc. Reports*), brought forward the idea that these substances are not strictly simple or elemental, but are compound radicals made up of, at least, two simple elements A and B. The element A was supposed to be identical with carbon, while B was connected with a *negative* weight, -2 , and it was suggested that it might be the ether of space. The conception of a negative weight has never been acceptable, and the hypothesis has for many years dropped out of sight.

According to another suggestion by C. S. Palmer (Proc. Colorado Scient. Soc.),* the existence is assumed of two sub-elements, to which the names "kalidium" and "oxidium" were given.

The hypothesis that hydrogen is the proximate ingredient of the elements was discarded by the author because the atomic weights have not been found to be exact

* The original article is abstracted in Venable's *Periodic Law*, and is referred to in footnotes in Palmer's translation of Nernst's *Theoretical Chemistry*.

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multiples of unity, and because hydrogen is inherently basic, and while it might be looked upon as the prototype of base-forming elements, it could not be the origin of the acid-forming elements. The author suggests that possibly hydrogen is a member of a complete independent series as yet unknown. The properties of the last element of this series, or *prefluorine*, were discussed by Palmer, and here he seems to have anticipated Mendeléeff. As to kalidium and oxidium, the two hypothetical components of all the elements, they are not regarded by Palmer as isolable forms of matter, but merely as representing antithetic qualities which are jointly responsible for the properties of the elements as we know them.

Within the last ten years investigations on the discharge of electricity through gases, especially by Sir J. J. Thomson and his school, have led to the development of a corpuscular theory of matter which, when more fully developed, will probably go far to

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account for many of the chemical characters of the elements and their periodic relation to atomic weight.

The following is a brief outline of the theory, of which details should be studied in *The Corpuscular Theory of Matter*, by J. J. Thomson.*

When any gas, enclosed in a highly exhausted glass tube so that the gas pressure is exceedingly small, is exposed to an electric discharge, the rays proceeding from the cathode in straight lines exhibit several distinctive properties. They cause a phosphorescence of the glass surface upon which they strike, and they are deflected by a magnet and by an electrified body in such a manner as to indicate that they consist of streams of negatively electrified particles. They also are capable of penetrating thin sheets of certain metals, and it becomes obvious that these particles are much smaller than the atoms or molecules of ordinary

* Constable and Co., 1907.

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gases. By experimental methods, of which an account is given in the work cited, Sir J. J. Thomson has shown that these small particles or "corpuscles," as he called them, have a mass which is only about $\frac{1}{1700}$ of the mass of a hydrogen atom. Each corpuscle carries a charge of negative electricity equal to that which is carried by an atom of hydrogen in the process of electrolysis. The separation of a corpuscle from an atom implies that the residue retains an equal positive charge. The carriers of positive electricity are, however, not corpuscles like those which carry negative electricity, but seem to be masses of which the least is comparable with the mass of an atom of hydrogen.

Negative corpuscles are producible not only from attenuated gases under the action of electric discharge, but are obtained from all kinds of matter, such as metals at a red heat, from heated oxides like lime, and from radio-active substances such as uranium and radium.

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The corpuscular theory of matter assumes that an atom of any element consists of a mass of corpuscles, which, being all electrically negative, repel one another, and must therefore be held together by the presence of positive electricity equivalent in amount, so as to produce that electrical neutrality which is the condition of the atoms in their normal state. There seems to be no definite knowledge at present as to the form in which the positive electricity exists in an atom, but as already stated no positively electrified body has been found having a mass much less than that of an atom of hydrogen. The distribution of negative particles within a sphere of positive electricity of uniform density has been the subject of mathematical investigation by the author of the theory,* with results which are extremely interesting from the point of view of the chemist.

When the presence of only one corpuscle

* *Phil. Mag.*, March, 1904,

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is assumed it obviously goes to the centre of the sphere. When a larger number are supposed to be present the cases in which they are confined to a plane passing through the centre of the sphere have alone been investigated.

It is shown in the paper referred to that five is the greatest number of corpuscles which can be in equilibrium in a single ring, but if others are placed within the ring then a larger number can maintain equilibrium in the ring. Thus, though a ring consisting of six corpuscles placed at the corners of a regular hexagon is unstable by itself, it becomes stable when one corpuscle is placed in the centre of the hexagon. A greater number will arrange themselves in a series of concentric rings, the number of corpuscles in each ring increasing as the radius of the ring increases.

The following table shows the numbers of corpuscles from one to sixty-nine, arranged in rings, the first row showing the numbers which may fall into one ring, the second

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series the numbers which may produce two rings, the third series those which produce three rings, and so on. (See next page.)

The numbers in the same vertical columns are repeated from series to series, the increased number of corpuscles in the additional ring forming the top line. Thus, in the first column, we find in the first series 5, 1; in the second series 11, 5, 1; in the third series 15, 11, 5, 1; and in the fourth 17, 15, 11, 5, 1. This similarity of arrangement means, that supposing atoms so constituted they would have similar properties, and the substances so formed would present the characters of a natural family, such as are to be found in the "groups" of the periodic table of elements.

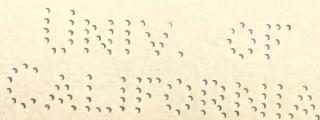
The relation of these configurations to the periodic scheme of the elements may be further shown as follows: Consider the properties of all the configurations which have 20 corpuscles in the outer ring. (See following table.) The smallest number with

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an outer ring of 20 is 59, and in this case the number within is only just sufficient to render the ring of 20 stable, consequently any disturbance from without may cause the outer ring to shed one negative corpuscle, whereby the residue of 58 acquires a charge of positive electricity, and the atom so constituted would present the character of a univalent positive element if it could retain the charge.

Passing from 59 to 60 the outer ring is more stable because there is one more corpuscle within, and the stability goes on increasing till there is a total of 67 corpuscles in the atom. The addition of one more corpuscle makes the arrangement unstable, because it now goes into the outer ring, which then consists of 21 corpuscles, and one of these can be easily detached, as in the case of the arrangement of 59 corpuscles already considered, and the result is another electro-positive atom.

Now the change from 59 to 67 corresponds



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to the addition of 8 corpuscles, but each addition of one corresponds to a new arrangement in the inner rings, as shown by the gradually increasing numbers in the lower rows of figures in the table, thus 16 to 17 in the second row, 13 to 14 in the third, 8 to 10 in the fourth, and 2 to 5 in the last row. So that as additional corpuscles are introduced the stability of the system increases till the total number is 67, while the addition of one more, just as the subtraction of one from 59, would produce instability.

It can be shown, then, that a series of atoms constituted on this hypothesis, with 20 corpuscles in the outer ring, would possess valencies corresponding to those assigned to the elements in the first two series in the periodic scheme ; thus :

Number .	59	60	61	62	63	64	65	66	67
Valency { .	+0	+1	+2	+3	+4	-3	-2	-1	-0
	-8	-7	-6	-5	-4	+5	+6	+7	+8
Total . .	8	8	8	8	8	8	8	8	8

The elements corresponding are :

He	Li	Be	B	C	N	O	F	Ne
Ne	Na	Mg	Al	Si	P	S	Cl	A

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The constant sum of positive and negative valencies in the series quoted seems to suggest Abegg's hypothesis of normal and contravalencies.

It must, however, be observed that the parallel between the hypothetical series shown above and the elements as they stand in the periodic scheme is, in the present position of the hypothesis, far from satisfactory, if only for the reason that there is a difference of only one corpuscle between the successive terms. The corpuscle has a mass equal to about $\frac{1}{1700}$ of the hydrogen atom, while the differences between the known elements He, Li, Be, etc., are much greater and are not uniform in passing from one element to the next.

Moreover, as pointed out by Thomson himself, the agreement between the hypothetical and actual, shown in the numbers just quoted, is merely accidental, and until the mathematical difficulties of an investigation in which the corpuscles are not confined

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to one plane have been overcome the theory cannot be further tested. The number of corpuscles in an atom is probably greater than the numbers assumed in the previous argument ; but on this point there seems to be no satisfactory evidence at present. There is, however, reason to think that whatever the number of corpuscles present the valency of the atom would vary periodically with the number, that is, with the atomic weight.

The word corpuscle which has been used throughout the previous statement, abstracted from Sir J. J. Thomson's book, is now usually replaced by the word "electron," a term originally introduced by Dr. Johnstone Stoney to designate the unit or atomic quantity of electricity. That this atomic quantity of electricity is separable from atoms of ordinary matter has been shown by work on the electric discharge through gases already referred to, and the idea that the electrical condition of matter, and its

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chemical activity, whether positive or negative, depend on the addition or removal of electrons has of late found much favour.

Sir William Ramsay,* adopting this hypothesis, has suggested a notation for representing chemical combination, the link between two atoms being represented by the appropriate number of electrons represented by the symbol E. Common salt, for example, would be expressed on this system by the formula NaECl . This seems to imply that the electron or electrons which are supposed to be the cause of valency and to incite atoms to combine are external to the atoms concerned. This is a proposition which would admit of argument, and has indeed been challenged. The evidence available for either view is at present only of an indirect character, and is not ripe for discussion.

Another way of treating the question is

* Presidential Address to the Chemical Society, *J. Chem. Soc.*, xciii, 774 (April, 1908).

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represented by the recent paper of Dr. James Moir.* The author assumes the cause of valency, at all events of the fundamental valency, of each element to be the presence in varying proportions of a sub-element of atomic weight $\frac{1}{112}$ or $\cdot 0089$. Denoting this by μ , then the univalent elements contain 1μ , the bivalent 2μ , the trivalent 3μ , and so on. The greater part of the mass of the atom is conceived as due to the polymerisation of an entity consisting of the hydrogen atom less μ . Denoting this by $\bar{H}$, then hydrogen is $\bar{H} + \mu$, lithium $7\bar{H} + \mu$, carbon $12\bar{H} + 4\mu$, oxygen $16\bar{H} + 2\mu$, neon $20\bar{H}$.

The atom of hydrogen is thus made up of $\cdot 9989 + \cdot 0089 = 1\cdot 0078$: oxygen is similarly $\cdot 9989 \times 16 + \cdot 0089 \times 2 = 16\cdot 000$.

The author has calculated the whole of the atomic weights in this manner, and the agreement with the recognised figures derived from the results of experiment is quite

* *J. Chem. Soc.*, xcv, 1752 (Nov., 1909).

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remarkable, a difference not exceeding .04 being found in the great majority of cases.

It is obvious that the resultant value for the calculated atomic weight will depend on the valency assumed for the element, and in the author's table certain elements seem to have been treated rather arbitrarily. Thus S has only 2μ assigned to it, P, As, and Sb only 3μ each, while Cr has 6μ , and V has 5μ .

On the whole, whatever may prove to be the physical significance of Moir's hypothesis, his numerical results are far more satisfactory than the earlier attempts to express by more or less complicated formulæ the relationship between the atomic weights. The majority of such formulæ contained constants or variables, which for the most part had no physical or chemical significance. Moreover, the atomic weights, accepted as the result of refined modern experiment, are in some few cases substantially different from those of thirty to forty years ago.

CHAPTER V

SPECULATIONS

“IF we be curious to know what matter is, we plunge at once into that deep which surrounds us on every side, and which never yet was fathomed by human intellect.

“With regard to its ultimate constitution we cannot hope to attain to a clearer conception than that which presented itself to the comprehensive but humble mind of Newton, and that transcendent philosopher has thus embodied the result of his patient investigations :—

““It seems probable to me that God in the beginning formed matter in solid massy, hard, impenetrable, movable particles, of such sizes and figures and with such other properties, and in such proportion to space as most conduced to the end for which He formed them ; and that those primitive particles being solids are incomparably harder than any porous bodies compounded of them ; even so very hard as never to wear or break in pieces, no ordinary power being able to divide what God Himself made one in the first creation.’”—DANIELL’S *Chemical Philosophy* (1843), p. 7.

FROM the foregoing chapter it appears that modern ideas as to the genesis of the elements, and hence of all matter, stand in strong contrast with those which chiefly prevailed among experimental philosophers from the time of Newton, and seem

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to reflect in an altered form the speculative views of the ancients.

Assuming the possibility of the evolution of matter, as we know it, from a primal essence, several questions require to be considered in order that the process may be pictured in terms of those forms of energy and those forces with which we are familiar. The earliest stages are too difficult, and must be passed over without an attempt at explanation ; for supposing a protyle, it is impossible to say what led to the first differentiation into discrete parts ; and if all were alike in mass and movement, what impressed one set of particles with the property of assuming the state called positive while another set acquired the power of becoming negative electrically. Nor can we say whether electricity is itself something super-added to matter or whether it is matter itself. Facts now at our disposal show that all matter is resolvable into the two parts, positive and negative, and the elements of

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the chemist of which all terrestrial matter consists are capable of being brought into a common scheme. The questions which admit of discussion are concerned with the relative probabilities of the different possible views as to the order in which these elements have been evolved, and the manner in which the negative protyle may be supposed to have co-operated with the positive toward the formative process. The question may also be considered whether it is probable that the elements have all been formed one after another in an order corresponding with the order of their atomic weights, and whether the process should be supposed to be of a generally uniform character throughout, or whether it is not justifiable to imagine that this uniformitarian view should be modified so as to admit the occasional operation of energy derived from sources other than those immediately and continuously concerned in the formative process.

In order to enter on this discussion a few

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facts should be recalled. The study of the radio-active elements, so far as it has gone within the few years that these substances have been recognised, has revealed one fact which is of great importance in connection with the question of evolution.

Radium, the best known of these elements, is a metal the compounds of which resemble those of barium, but with the important difference that it undergoes spontaneous disintegration and decay, giving off particles of helium and a gaseous emanation which is ultimately resolved into helium and nothing else. What may be the residue left after the escape of the emanation from radium is not known with certainty, but it is believed to be one of the common metals. Radium, then, seems to contain within its atom a store of helium, the escape of which is attended by the liberation of an enormous amount of energy, so that the process may be compared with the decomposition of an "endothermic" chemical compound,

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with the qualification that the energy liberated is vastly greater than the amount liberated in any known chemical process.

The constitution of radium is probably imitated by that of the other radio-active elements, actinium, polonium, etc., which, in respect to their chemical characters, are at present very imperfectly known, though there is reason to believe that they agree in possessing metallic characters.

It seems to be established that metals of the ordinary type, such as potassium and the rest of the alkali metals, and others under special conditions, emit β rays similar to those of radium, which are attributed to the expulsion of negative particles or electrons; but there is at present no evidence that anything corresponding to an emanation resolvable into helium escapes from them. It is conceivable that the instability of the radio-active elements may be due not only to their larger atomic mass, but to their peculiar constitution, the helium atoms expelled

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from radium, for example, being apparently ready formed within its larger atom, which would thus possess a sort of grained structure, while in ordinary inactive stable elements the electrons may be supposed imbedded in the positive shell in positions from which they are not so readily dislodged.

From the experiments of J. J. Thomson it appears that helium itself, like other gases, under the influence of the electric discharge gives negative corpuscles in the rays from the cathode, and positively charged particles simultaneously. Hence helium and the rest of the argon group are also probably constituted of positive and negative protyles, and the chemical inactivity of these elements must be attributed to the peculiar intimate kind of association in which the two protyles exist.*

* It would seem, however, that dissociated as they are under the action of electricity some chemical activity ought to be induced under these circumstances, and the reason why it has not been observed is that the amount thus dissociated is too small to be recognisable by any ordinary chemical agent. Ramsay, "L'Helium," *Ann. Chim.* [7] xiii, 38 (1898).

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Supposing Crookes' figure of eight to be accepted as the basis of a diagrammatic representation of the changing conditions under which the protyle condenses into atoms of matter it seems to need some modification. For inasmuch as condensation, mechanical or chemical, is always accompanied by loss of energy to the system, every time that an element is formed an evolution of energy takes place, which, whether it take the form of heat or of electrical potential, must temporarily arrest the process of condensation till it has in some way become dissipated. It would also seem probable that, supposing a similar constitution for both, the formation of a large atom from protyle must be attended by the separation of a larger amount of energy than is the formation of a small atom. The successive steps of the process by which the elements are severally produced according to the order of their atomic weights must therefore become slower and

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slower, so that the intervals occurring between the deposition of one atom and the next will become necessarily greater. Hence the distribution of the elements at *equal* intervals along the curve does not seem to harmonise with probability. The periods represented by the lemniscate track should increase in descending so as to bring in the element of time.

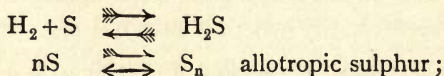
It might be argued that if the elements of high atomic weight were formed slowly they would probably be more stable than those of smaller atomic weight formed more quickly, or at least equal in stability. This, however, does not seem to be the case, for the radio-active elements are all found among those of the highest atomic weight, so that some elements seem to have been formed hastily with an internal constitution not framed to assure permanence. It is therefore conceivable that the process of condensation did not always result in the formation of one element at a time; a non-

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metal may have attended the production of a metal, or an element of high atomic weight may have come into existence simultaneously with one of low atomic weight.

An analogy is afforded by the processes of polymerisation of ordinary matter. For example, aldehyde C_2H_4O is convertible simultaneously into paraldehyde $(C_2H_4O)_3$ and metaldehyde $(C_2H_4O)_n$, the change being attended by evolution of heat and contraction.

The condensation of protyle must, however, be imagined as an interaction of positive and negative particles, and an analogy, as far as it goes, might be found in the action of hydrogen on sulphur at an elevated temperature. Here we should have balanced actions :



while the proportions formed, and the state of equilibrium maintained, are under the operation of the law of mass action.

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We have already seen that of the known elements those which exhibit the metallic character are by far more numerous than those which are definitely non-metallic, and this seems to suggest that probably the constitution of the metals is generally more stable than that of the non-metals. But inasmuch as radium and the other radioactive elements, which are all of high atomic weight, are actually in process of spontaneous disintegration, they must differ from the rest in regard to internal constitution, and a suggestion has already (p. 112) been made as to the possible cause of their instability.* These elements, radium, actinium, polonium, are now all that remain of what was probably in earlier stages of creation a more

* It is not very clear why the disintegration should take place atom by atom, or, in other words, what it is that determines the explosion of one atom rather than another in its immediate neighbourhood, and having presumably the same constitution. It does not appear to be the result of mass action, for the products of disintegration pass away as soon as liberated, and do not seem to accumulate in the residue.

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numerous family of similarly radio-active bodies. For as radium yields helium the first term of the chemically inactive series, it seems legitimate to suggest a similar origin for neon, argon, krypton, and xenon. It is improbable that any traces of these elements remain among the constituents of the earth. Their formation must have been the result of a process of condensation of the hypothetical protyles, but they were probably formed at an early stage of the process of evolution, as by-products in the operations from which issued the common permanent elements of relatively low atomic weight, which at this day constitute the basis of all terrestrial and most celestial things.

The disintegration of these large atoms must have been attended by the liberation of large stores of energy greater even than that which is known to be set free from radium, and this liberation of energy must have been a disturbing agency, possibly

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intermittent, which may well be credited with some of the irregularities in the development of the scheme of creation which resulted in the elements of our system.

Substances of this character are already known among the products of the disintegration of radium, all of which are rather short-lived, but probably have a definite atomic weight. Of these the most important is the "emanation" from radium. This is a chemically inert gas which may be condensed at a low temperature to a solid, and the period of half transformation of which is 3.8 days. It is ultimately resolved wholly into helium, and in the process of transformation gives out heat at the rate of 75 gram calories per hour, at its maximum, for the emanation released from 1 gram of radium.* This enormous liberation of energy in so concentrated a form may well be credited with the power of arresting or promoting, according to circumstances, a

* Rutherford's *Radio-activity*, 2nd ed., p. 431.

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process of condensation proceeding in any material in contact with the emanation. Such a change on a large scale may have affected the nature of the products hypothetically resulting from the condensation of "protyle."

To some such agencies may be reasonably attributed Mendeléeff's eighth group, the anomalous atomic weight of tellurium, the peculiarities of the cerium group of earth metals, and even the eccentricities of individual elements such as mercury or thallium.

Turning now to the elements of lowest atomic weight, the spectroscope has shown that hydrogen and helium appear more widely distributed in nebulæ and stars than elements of greater atomic weight, such as calcium, magnesium, and iron. But the evidence concerning the existence of other elements, to which names such as asterium, nebulium, and coronium have been given, is, to say the least, very uncertain. Hence

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the hypothesis of Jessup (p. 84) is founded on a very insecure basis. The latest announcement of the kind comes from Professor Wolf, of Heidelberg, and attention has been drawn to it in *Nature* by Professor Brauner, of Prague.* From experiments on centrifugal rotation of a mixture of gases, by Lobry de Bruyn and others, it appears to be established that the constituents of such a mixture are partially separated by very rapid rotation, the gas of higher density, and hence greatest molecular weight, present becoming concentrated in the periphery as the radius of rotation is increased. Wolf finds that the ring nebula in Lyra consists of four gases, which, owing to rapid rotation of the ring, have become separated into four different layers. The smallest ring A, representing the innermost part, is composed of an unknown gas. The next larger, B, consists of hydrogen; the next, C, external to B, con-

* *Nature*, lxxx., 158 (April 8, 1909).

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sists of helium ; while the outermost ring, D, consists of another unknown gas. So that A must be lighter than hydrogen, and D must be heavier than helium.

Professor Brauner reminds us that Mendeléeff supposed the existence of an element with atomic weight 0.4, or one-fifth the density of hydrogen, but belonging to the inactive series like helium ; and this element he provisionally identified with Young's coronium, a gas hitherto recognised only in the sun. The nature of the denser gas leaves room for speculation. Brauner himself suggests a gas with a smaller atomic weight than helium, but having a larger molecular weight. This implies that its molecule must be composed of more than one atom, and it therefore would not fall into the argon family. I have recently* suggested the possibility of an element standing toward the halogens in the same

* "Mendeléeff Memorial Lecture." *J. Chem. Soc.*, xcv, 149 (1909).

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relation, as regards atomic weight, as hydrogen to the alkali metals. This would have a density about 2.8, and a molecular weight 5.4. Mendeléeff, in his latest speculations (1905) concerning the possibility of still undiscovered elements, suggested the existence of an element of the halogen group with atomic weight about 3. The non-metals are notoriously more difficult of recognition than elements of metallic or metalloidal character. But the identification of oxygen and nitrogen, and recently of sulphur,* in some of the hotter stars lends some support to the idea that the spectrum observed by Wolf may be due to an element of this kind.

In Mendeléeff's latest table of the elements (pp. 46-47) γ is supposed to be a very light gas of the same monatomic constitution and inactive character as helium, and may be identified hereafter with "coronium," which is found in the sun's coronal

* Lockyer, *Proc. R. Soc.*, lxxx, 50, 1907.

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atmosphere. This gas, according to Mendeléeff, would have a density about 0.2, and therefore a molecular weight and atomic weight about 0.4, or about one-tenth that of helium.

The α in this table is the "ether" of the physicist for which Mendeléeff, disregarding conventional ideas, assumed a molecular structure with an extremely small density and atomic weight. The properties attributed to the ether, which pervades all space and penetrates through all ordinary matter, show, however, that, whatever it may be, it is not a gas. α may stand for the present purpose to represent the hypothetical positive protyle, while $\bar{\alpha}$ may be placed in the corresponding position at the end of Series 0 as the symbol of the other, negative, parent of common matter.

Having now cleared the ground, we may proceed to consider what are the most probable lines along which evolution may be supposed to have been accomplished,

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and a few general principles must be laid down before attempting to display any general scheme.

1. Mendeléeff's periodic law is applicable to a large number of elements, though, strictly speaking, the scheme does not provide for all. The properties of the elements are undoubtedly determined partly by atomic weight, but they are also influenced, perhaps in a greater degree, by what must be supposed to be their internal constitution, or the arrangement of the electrons within the atom. It does not, however, follow that they were evolved one after another in the order shown in the table. The curves of Reynolds and Crookes are much too simple in assuming the operation of uniform physical conditions from first to last. Whereas from the irregularities and anomalies noticeable in so many parts of the scheme it seems more likely that the processes of construction assumed several forms, and were liable to interruption or accelera-

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tion from causes which have been already referred to.

Thus while a large number of the elements may have been produced by simple condensation together of positive and negative protyle, others were probably formed by disruption of big atoms, a kind of depolymerisation, or again by special and peculiar processes due to the disturbing effects of energy introduced by such disruption.

2. The radio-active elements were probably formed by direct condensation of protyle, but this condensation occurring without the loss of so much energy as may be supposed to occur during the formation of the common stable elements, an unstable endothermic structure resulted.

3. Condensation probably occurred in the order of the natural families, that is, down the vertical columns of Mendeléeff's groups, so far as the cases of closely allied elements are concerned. It is, for example, highly probable that sodium was formed immedi-

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ately after lithium, followed by potassium, rubidium, and cæsium.

The idea that the metals owe their obvious community of characteristics to the presence in them of a common constituent is of no recent date. It was the radical principle of the ancient doctrine concerning transmutation. The alchemists believed that the "base" metals and the "noble" metals differed only by reason of the presence in the former of some kind of disease or impurity which obscured the pure metallic qualities of their noble relatives silver and gold. The notion was quite seriously referred to by Davy in the early part of the nineteenth century, and is one which has been repeatedly revived.

The families of negative elements were probably produced in a similar manner, though in this case the modification of character which attends increase of atomic weight is more marked, the change amounting to a partial change of function, as may

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be seen by comparing together sulphur and tellurium, or still more obviously phosphorus with bismuth, or silicon with lead.

4. It seems to be agreed that a limit is set to the magnitude of atomic weight in consequence of the general instability of elements with large atoms. Uranium stands at present at the end of the known series. It is believed to be undergoing spontaneous disintegration, but it is evidently more stable than radium, which is supposed to be derived from it, and this affords direct evidence that constitution has more to do than mere mass in determining the character of an atom.

Here it may be remarked that both radium and polonium seem to be in process of formation now and always from uranium, and in the absence of information as to the nature of the change a question arises as to the real nature of the primal stuff. Is it uranium itself or something of still higher atomic weight existing in small quantity in uranium?

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5. The elements of the argon group were pretty certainly products of devolution from substances of high atomic weight, most of which have become extinct so far as this earth is concerned.

Probably a few other elements of the ordinary type, e.g. lead, represent the residues of this disruptive operation.

6. Evolution of some families may be assumed not to have proceeded by the simple accretion of matter or electrons as suggested (3), but starting from one or other of the typical elements the course of condensation may have followed more than one path, while preserving the same general character of product. Take the case of the iron metals, for example. The ordinary arrangement of the metals in the periodic scheme separates iron, nickel, and cobalt, on the one hand, from copper and zinc ; and on the other from manganese and chromium. But these metals form an isomorphous group in which the isomorphism is repeated in the

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salts corresponding to the ferrous, as well as to the ferric salts and to the chromates as far as they go.

The valency of manganese has been misrepresented on the basis only of the isomorphism of permanganate with perchlorate in order to force it into the halogen group. Placing these metals in the following order the reader is reminded of their close inter-relationship, as well as the gradual decline of valency, and of the permanence of the higher oxides among them.

	Valency.				At. Wt.	Density.	At. Vol.
Chromium .	II	III	IV	VI	52·0	6·9	7·5
Manganese .	II	III	IV	VI	54·9	6·85 to 8·0	7·4
Iron .	II	III	IV	VI	55·8	7·8	7·1
Cobalt .	II	III	IV	VI ?	59·0	8·7	6·8
Nickel .	II	III	—	—	58·7	8·8	6·7
Copper .	II	—	—	—	63·6	8·9	7·1
Zinc .	II	—	—	—	65·4	6·9	9·5

Cobalt appears to be related to manganese much in the same way as nickel to iron. The only metal from which the whole group could be descended is aluminium, which is isomorphous with iron in the ferric

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state, but has the lower density, 2.6, and lower melting-point, 650°, which agree with its lower atomic weight, 27.1.

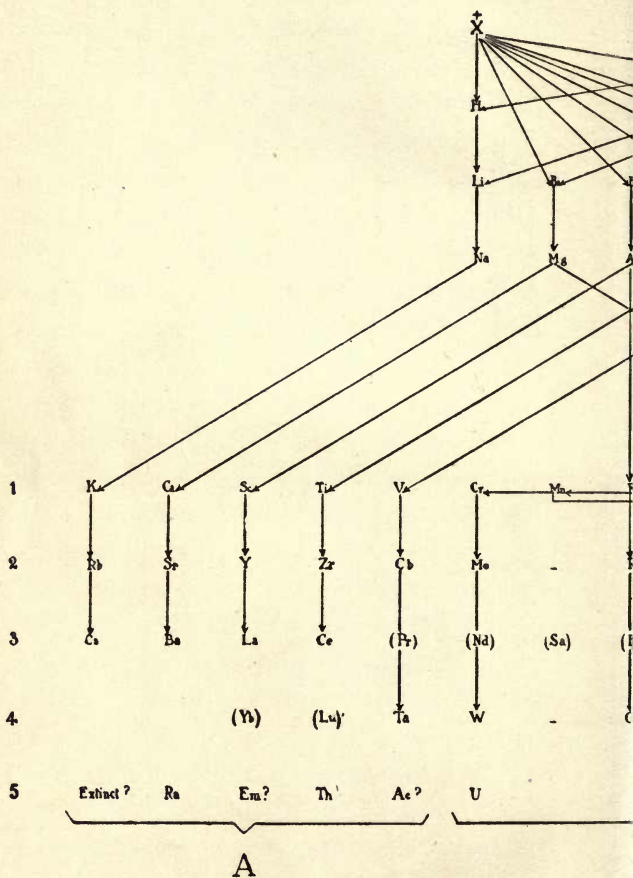
In the following table, which preserves the chief features of the periodic scheme, an attempt is made to indicate the probable order of evolution. The two lateral divisions marked A contain the families which are supposed to have been formed by direct process of condensation, the successive elements being produced one after the other, as indicated by the arrows. The middle division, B, contains elements which for the most part are supposed to have been produced indirectly or irregularly. Concerning the "rare earths," no attempt has been made to trace their origin, though it is possible that they are descended from aluminium through scandium, yttrium, and lanthanum. χ stands for the hypothetical pre-fluorine referred to on pages 122-3.

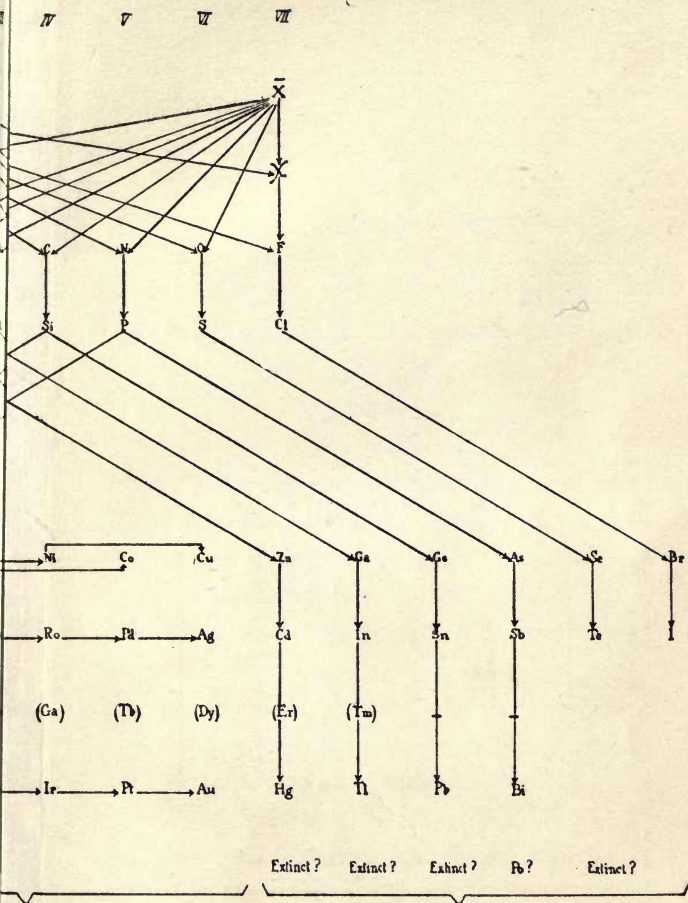
The diagram speaks for itself, but it may be as well to point out that the first eight

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elements, including hydrogen, are supposed to be formed by direct union of $\bar{x}^+$ and $\bar{x}$, the two hypothetical protyles; and this is indicated by the lines terminating in each case in an arrow-head. The next seven are supposed to result from condensation upon the body of the already formed atom of more protyle, positive or negative, according to the structure and requirements of the atom which forms the nucleus.

According to this view sodium was formed from lithium, magnesium from beryllium, and so forth. A similar development is supposed to proceed downwards into the successive families ranged in the departments of the table marked A, the order of succession being indicated by arrow-heads. Where no arrow-head is shown no opinion is expressed, although the line may pass through a symbol. For example, tantalum is supposed to be the lineal descendant and derivative of columbium (niobium) without implying any view in regard to praseodymium.

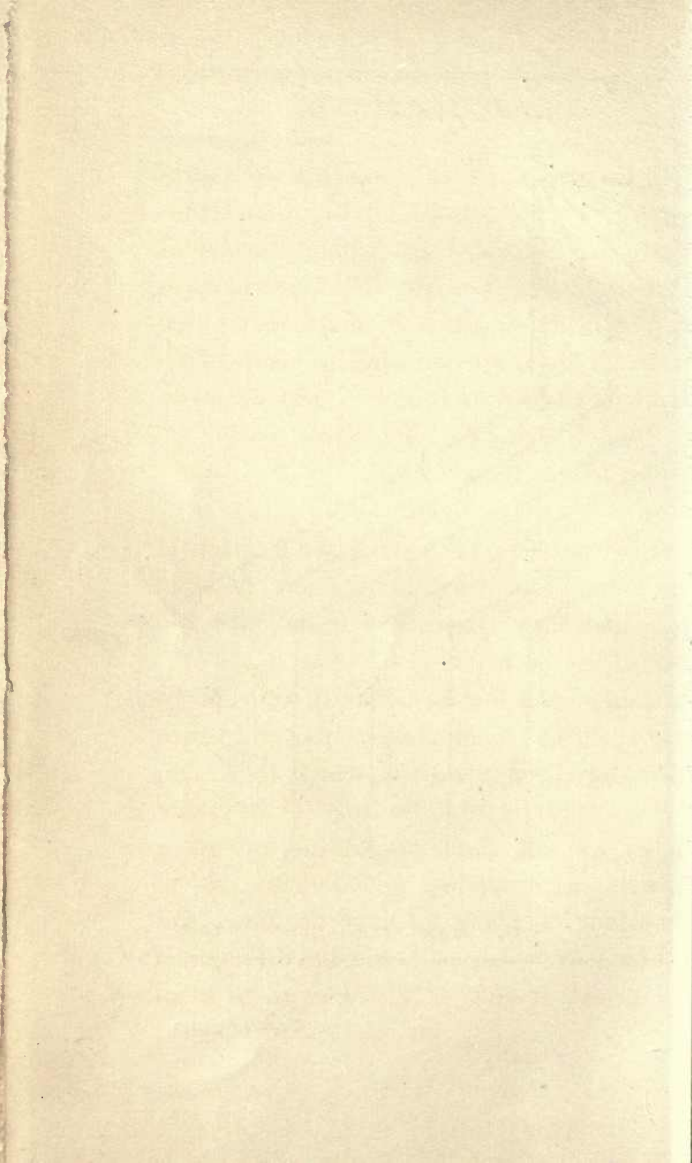




B

A

To face page 132



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In the division B the elements are represented as being formed in the order represented for the most part along horizontal lines, in most cases the development proceeding in the direction of increasing atomic weight. The most doubtful case is the derivation of ruthenium from iron, but the series

Ru - Ro - Pd - Ag

is parallel to the series

Os - Ir - Pt - Au

How the elements on the last horizontal line came into existence it is not possible to suggest in a diagram, but the probable process has been sketched in par. 2.

From what has gone before it seems probable that the chemical elements, and hence all material substances of which the earth, the sea, the air, and the host of heavenly bodies are all composed, resulted from a change, corresponding to condensation, in something of which we have no direct and intimate knowledge. Some have imagined this primal essence of all things to be iden-

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tical with the ether of space. As yet we know nothing with certainty, but it is thought that by means of the spectroscope some stages of the operation may be seen in progress in the nebulae and stars. This affords a wide field for speculation, and possibly our knowledge may never become more certain than it is to-day. In some departments of thought, however, we must be content with circumstantial evidence, which, if only sufficient in amount, may serve as a satisfaction to the mind.

Until quite recently the elements of the inorganic world were supposed to be fixed, immutable with the lapse of ages or under the mighty forces concerned in the making of worlds. But within a few years we have learned that some atoms, at any rate, are not permanent, but are continually crumbling away.

There seems in all this no obvious parallel between the changes which have led to the formation of the elements and the evolution

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of living beings. In organic evolution spontaneous variation of form and function, and the struggle for existence, leads to the survival of the fittest. If some of the elements are actually exposed in nature to the attack of α or β particles, atoms of helium, or something else, moving with immense velocity comparable with that of light, they may be breaking down.

As yet it is impossible to say whether all may not be suffering a slow waste which in the long run must lead back to the primal chaos.

“How real existence is to be studied or discovered is, I suspect, beyond you and me. But we may admit so much that the knowledge of things is not to be derived from names. No ; they must be studied and investigated in themselves” (Socrates, in Plato's *Cratylus* ; Jowett's translation).

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